Nature UNBOUND

the impact of ecology on Missouri and the World

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STUDENT BOOK

On the cover: A northern harrier swoops down on a greater prairie-chicken. This connection—between a predator and its prey—is one of countless interactions that occur in nature. By studying how living things interact with the living and nonliving parts of the environment, ecologists help further our understanding of how nature works.

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STUDENT BOOK

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A fisheries biologist uses an electronic wand to check for a wire tag embedded in a lake sturgeon's flesh. Each tag is only 3 millimeters long and has a specific code that helps the biologist identify individual fish.

BIG IDEAS:

- Ecology is the study of how nature works.
- Ecologists study things as small as individual organisms or as large as the biosphere.
- Ecologists make observations, ask questions and collect data.
- Understanding ecology is important for many reasons.

What IS ECOLOGY?

A boat drifts slowly in the Mississippi River. On deck, two ecologists attach a radio transmitter to a lake sturgeon. The transmitter will help them track the fish's movements and answer questions about what habitats it uses to feed, rest and reproduce.

An airplane swoops low over the cattails of a marsh. As the pilot keeps the plane a mere 30 meters off the ground, an ecologist seated next to him records the number of each kind of duck he sees. These counts will help the ecologist estimate whether duck numbers are increasing, decreasing or remaining stable.

Near Columbia, an ecologist watches a gray squirrel through her binoculars. She takes detailed notes about what the squirrel eats, where it moves and when it's active. This data will help her learn how much gray squirrels compete with other kinds of mammals for food and resources.

On a prairie near Joplin, an ecologist watches a wall of flame race up a hillside. He is studying how prairie plants respond to combinations of fire and grazing. In a few weeks he'll move a herd of bison onto the hillside and monitor how the plants respond.

Deep in the Ozarks, an ecologist maneuvers a cherry picker up into the forest canopy. Once there, she uses a device to measure the rate of photosynthesis occurring in the leaves of a white oak tree. This information will help her estimate how much carbon the forest removes from the Earth's atmosphere.

We can learn much about ecology from these accounts. Although they go about it in different ways, each of these ecologists is trying to learn more about how nature works. To understand nature, ecologists study individual living things, groups of living things or large landscapes. Ecologists make observations, ask questions and collect data. Studying ecology helps answer questions important to the survival of all organisms, including humans.

Ecology is the study of how nature works.

Ecologists divide nature into two basic parts: living and nonliving. The **biotic** (living) part of nature is composed of plants, animals, fungi, protists and bacteria—anything that is alive. The **abiotic** (nonliving) part is composed of the physical and chemical components of the environment, including water, sunlight, temperature and soil chemistry *(Table 1.1)*.

BIOTIC	ABIOTIC
Plants	Sunlight
Animals	Water
Fungi	Temperature
Bacteria	Soil Chemistry
Protists	Oxygen

Table 1.1—Examples of biotic and abiotic parts of nature

Water is an important abiotic part of a wetland. The amount of water, its depth, and how long it stays around influence the kinds of living things found in a wetland. Muskrats and cattails both need water to survive. If a wetland dries up, cattails in the wetland soon die, and muskrats leave the wetland to look for new homes. In turn, living things can influence properties of water. Muskrats use plants, such as cattails, for food and to build their houses. In doing so, muskrats remove patches of vegetation and create areas of open water. With less vegetation to restrict air flow, more oxygen is mixed into the water when wind causes waves. Removing vegetation also removes shade, allowing sunlight to penetrate the water, increasing its temperature.

From this example, we learn a key theme of ecology: Any living thing is affected by and responds to both biotic and abiotic parts of its environment. Likewise, abiotic parts of the environment are affected by living things. Ecologists seek to understand these relationships.

Ecologists study things as small as individual organisms or as large as the biosphere.

The way ecologists study nature depends on how narrowly or broadly they focus their observations and experiments. At the narrow end, an ecologist might focus on a single living thing. At the broad end, an ecologist might focus on the earth as a whole. To accomplish their studies, ecologists organize nature into different levels of focus *(Figure 1.1)*.

All matter—from a chunk of granite underfoot to a bird overhead—is composed of **atoms**. There are over 100 different kinds of atoms, such as carbon, hydrogen and oxygen. Atoms combine with other atoms to form **molecules**. Water, carbohydrates, proteins and lipids are molecules important to living things. Molecules assemble together to form **organelles**, microscopic structures in a cell that perform specific functions. Mitochondria are organelles that generate energy for living things. Groups of organelles form **cells**. All living things are made of cells. Some, such as bacteria, consist of a single cell. Others, such as humans, consist of trillions of cells. Cells assemble together to form **tissues**. Muscle is a tissue composed of cells that have the ability to contract. Tissues assemble together to form **organs**. The heart is an organ composed of muscle, fat and nervous tissues. Different organs working together form an organism. This is the point where ecologists become interested.

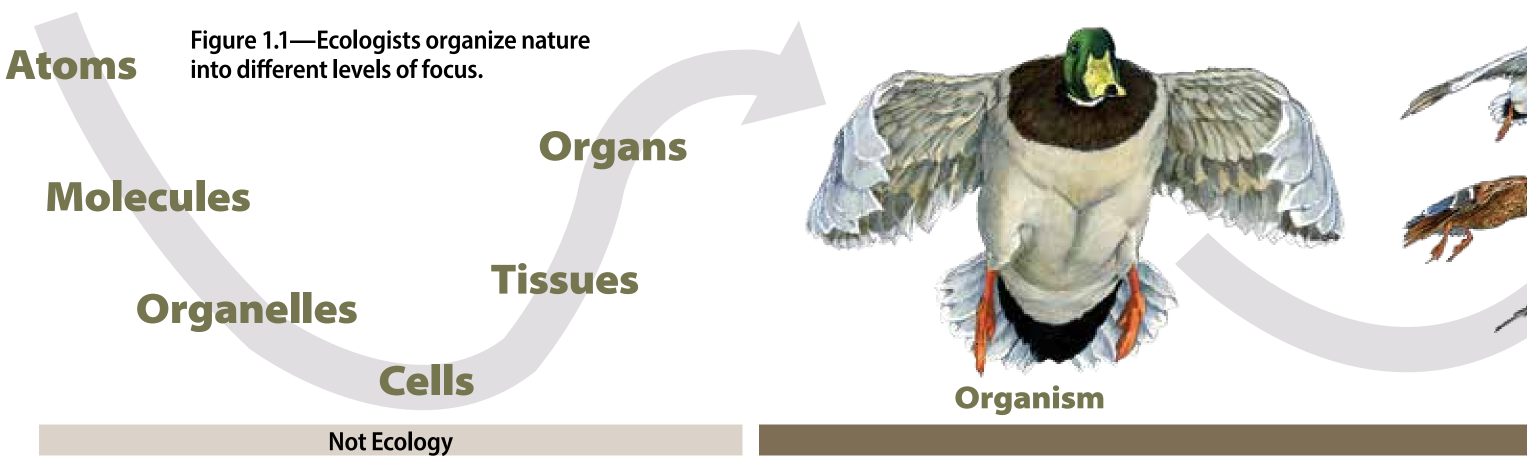


Figure 1.1—Ecologists organize nature into different levels of focus.

Organisms

Like all organisms, muskrats are adapted to the environment in which they live.

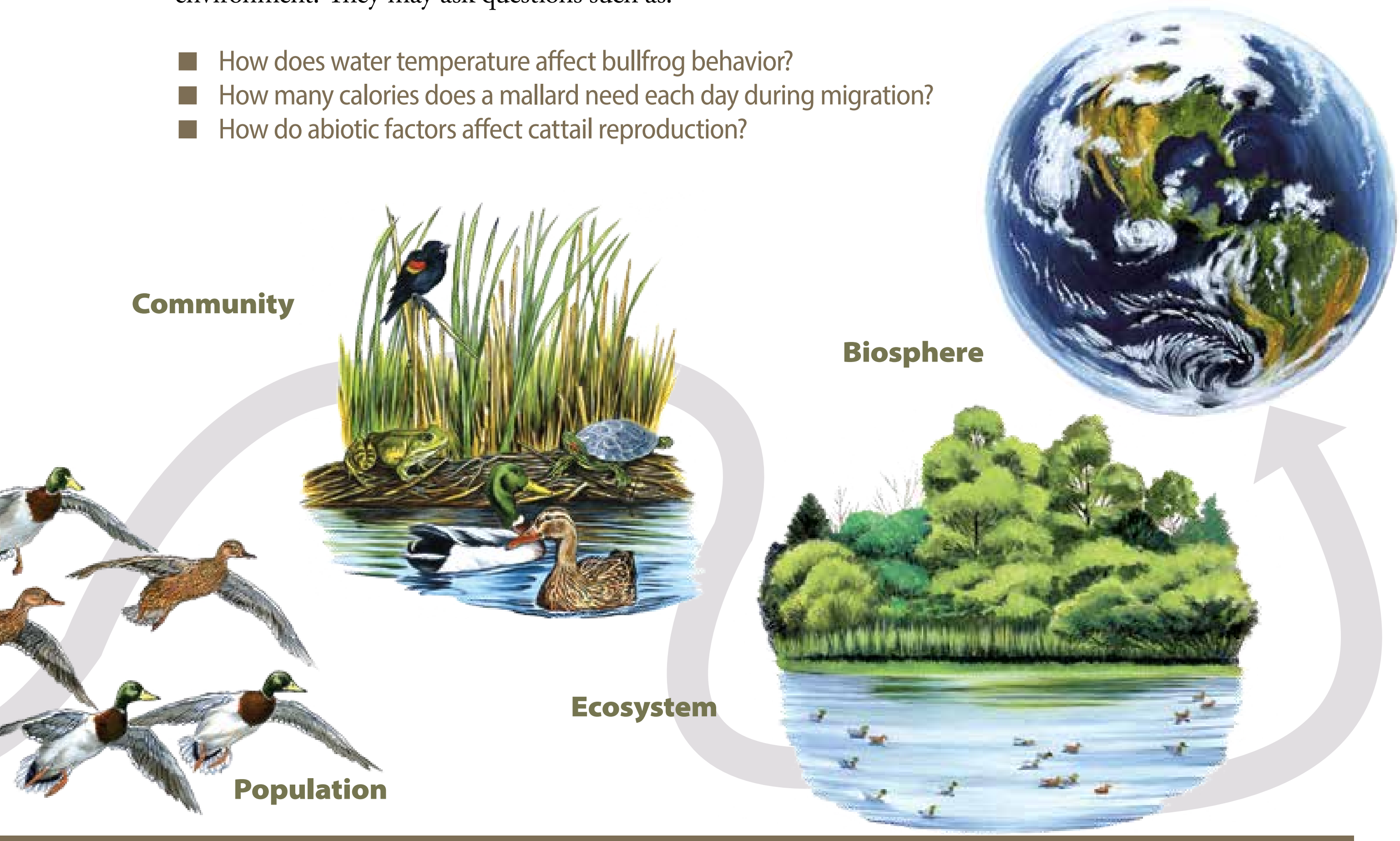
An **organism** is a single living thing. A bullfrog, a mallard and a cattail are all organisms. An organism is the smallest unit of life that can sustain itself. Cells, tissues and organs are alive, but none of these can live for long when they are removed from the organism of which they are part. This doesn't mean that single cells can never be organisms. Bacteria, many protists and some fungi function quite well as single-celled organisms.

To survive, all organisms need water, energy, nutrients and space in which to live. The way these items are obtained varies from one kind of organism to the next. Cattails, muskrats and mink all need energy, though they obtain it in different ways. Cattails get their energy by using sunlight to turn water and carbon dioxide into sugars. Muskrats get most of their energy from eating plants, including cattails. Mink get most of their energy from eating other animals, including muskrats.

All organisms have adaptations that help them survive in a particular environment. Muskrats have a dense coat of fur that keeps them warm, waterproof and buoyant in water. They have webbed hind feet to propel them while swimming and a flattened tail that can be used as a rudder. Muskrats can reduce their heart rate, store oxygen in their muscles and tolerate high levels of carbon dioxide in their blood, all of which enables them to stay underwater for up to 17 minutes. Each of these adaptations helps muskrats survive the wet environments in which they live.

Ecologists who study organisms try to learn how living things are affected by and respond to their environment. They may ask questions such as:

- How does water temperature affect bullfrog behavior?
- How many calories does a mallard need each day during migration?
- How do abiotic factors affect cattail reproduction?



Populations


All the mallards living together in the same place at the same time form a population.

A group of the same kind of organisms living together in the same place at the same time forms a **population**. All the bullfrogs living in a wetland make up a population. The cattails, mallards and green darner dragonflies living in the same wetland make up three different populations. Populations are made up of individuals of the same species. If two organisms can mate and produce fertile offspring, they are likely members of the same species.

Sometimes barriers, such as mountain ranges, bodies of water or freeways separate one population from another. For example, the population of green sunfish living in one wetland is easily separated from the population of green sunfish living in a different wetland. In this example, dry land is a barrier separating the two fish populations.

More often, ecologists define the boundaries of a population based on the question they are trying to answer. An ecologist interested in learning how many Canada geese nest in a particular wetland would use the wetland's boundaries to define the population of geese he wants to study. However, an ecologist wanting to learn how a statewide hunting regulation affects goose populations might use Missouri's boundaries to define the population she needs to study to answer her question.

How much space an individual organism needs to survive also helps define the boundaries of a population. Ecologists may need just a few hectares to study a population of aquatic insects because the insects don't need much space to grow, survive and reproduce. However, because river otters need more space in which to live, an ecologist might need an area of several thousand hectares to study otters. And, an ecologist studying populations that migrate, such as mallards, might need a study area of several thousand square kilometers.

Populations have several characteristics that ecologists study. One of the most important is **population size**, which is the number of individual organisms that make up the population. Population size grows or shrinks in relation to how many individuals move into the population (through births or immigration) and how many individuals leave the population (through deaths or emigration).

Ecologists who study populations try to learn what factors contribute to an increase or decrease in the population's size. Understanding these factors can help prevent extinctions, set hunting limits and control pest populations. When studying populations, ecologists ask questions such as:

- What factors affect snapping turtle populations?
- How many river otters can the Grand River watershed support?
- How will a new hunting regulation affect Canada goose populations?

Communities

A group of different populations living in the same place at the same time forms a **community**. The populations of bullfrogs, cattails, mallards, muskrats, dragonflies, cottonwood trees and all other populations living in a wetland form a wetland community. Just like populations, the boundaries of communities are often defined by a natural barrier or by the question an ecologist is trying to answer.

Individual populations living in a community are tied to each other through many different kinds of interactions. For example, some populations are tied together by feeding relationships. A population of muskrats is tied to a population of cattails when muskrats feed on cattail stems, leaves or roots. Likewise,

populations of mink are tied to muskrat populations when a mink preys upon a muskrat kit.

Other populations are tied together by competition for a needed resource. For example, populations of plants might compete for sunlight, populations of songbirds might compete for nesting sites, and populations of predators might compete for prey.


Canada and snow geese are among many populations that make up a wetland community.

Sometimes two populations are tied together by a relationship that benefits both populations. Smartweed is a plant that grows in wetlands. Ducks benefit from smartweed by eating its seeds for energy. Although most seeds are digested, some pass through the duck's gut and are deposited when the duck excretes wastes. Because the seeds are often deposited far from the original plant, smartweed is spread to new locations, which keeps parent plants from competing with their offspring for water, sunlight and other resources.

Ecologists who study communities try to figure out how various interactions affect the populations involved. When studying communities, an ecologist might ask:

- Do red-winged blackbirds and marsh wrens compete for nesting sites?
- Do ducks help disperse the seeds of wetland plants?
- How are mink populations affected by changes in muskrat populations?

Ecosystems

A community along with the abiotic factors of the environment forms an **ecosystem**. For example, the populations of bullfrogs, cattails, mallards, muskrats, dragonflies, cottonwood trees and all other organisms living in a wetland *plus* the sunlight, water, temperature, humidity and other abiotic factors at this location form a wetland ecosystem. Ecosystems in Missouri include prairies, glades, woodlands, forests, caves, wetlands, rivers and streams.


A wetland ecosystem is composed of living things, such as cattails and herons, and nonliving parts of the environment, such as water and sunlight.

Although ecologists generally think of ecosystems as large, complex structures, something as small as a rotting log or the inside of your digestive tract is also an ecosystem. Regardless of their size, ecologists who focus at this level study how energy is transferred from the sun through

different organisms that feed upon each other. Ecologists also study how atoms essential for life—such as carbon, nitrogen and phosphorus—cycle through both abiotic and biotic parts of the ecosystem. They may examine how physical processes, such as fire or flooding, affect the communities in the ecosystem. Ecologists who study ecosystems may ask questions such as:

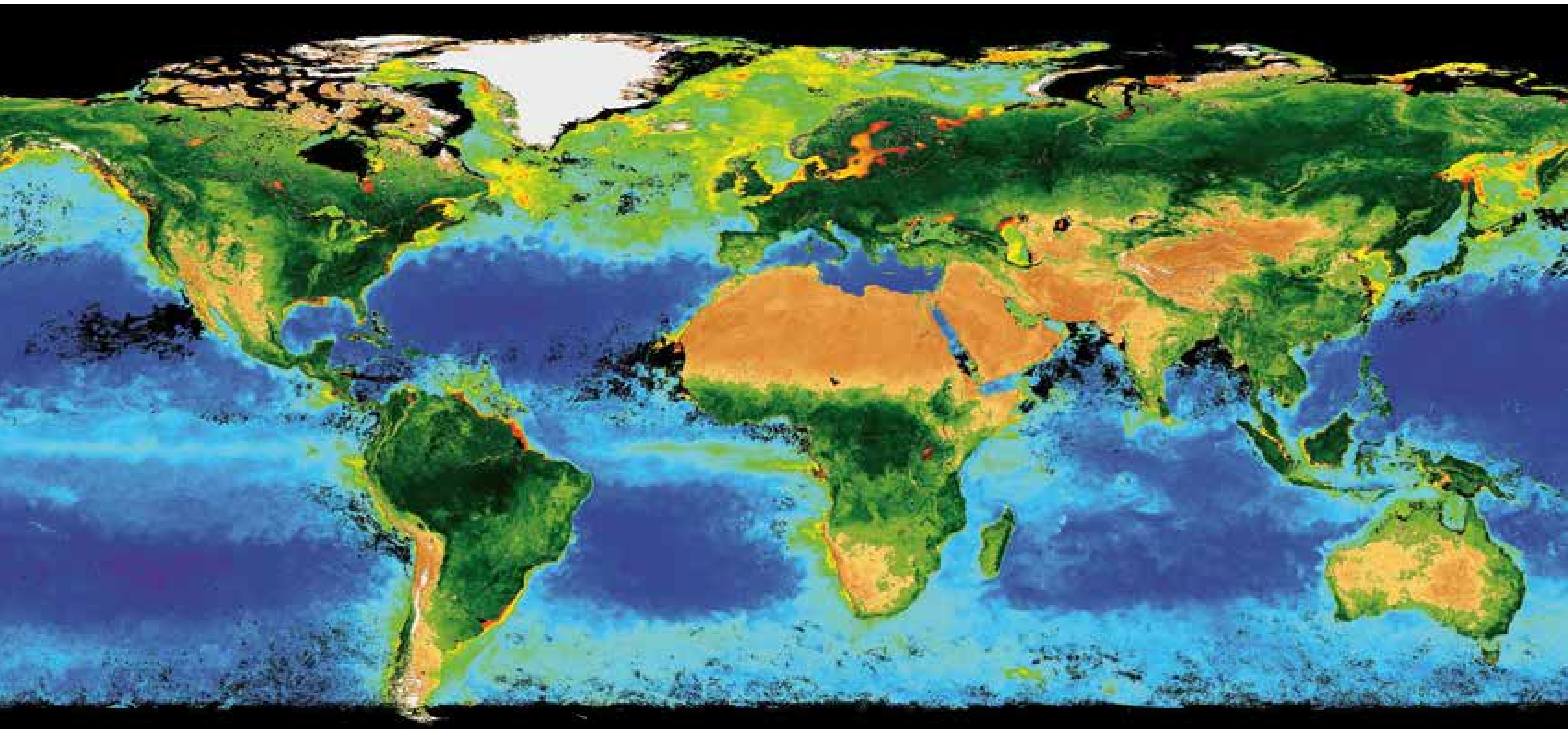
- How does flooding affect wetland plant communities?
- How much energy from sunlight is converted to plant mass in a wetland?
- How fast does nitrogen move through a wetland ecosystem?

Biosphere

Wind, water and the migration of organisms link ecosystems together. All the ecosystems on Earth form the **biosphere**, the layer of our planet that supports and contains every living thing. The biosphere extends anywhere life exists, from the deepest ocean trench to the tallest mountain—about 9 kilometers below sea level to about 5.5 kilometers above sea level.

Ecologists who focus on the biosphere try to understand how global processes—such as the movement of materials by ocean currents or the warming of the Earth's atmosphere—affect different ecosystems. They study how something that happens in one ecosystem affects other ecosystems. In going about these studies, an ecologist may ask questions like these:

- How much carbon do wetland plants remove from Earth's atmosphere?
- How much nitrogen flowing into the Gulf of Mexico comes from Missouri?
- What role do Missouri's wetlands play in shorebird migration?



Earth's biosphere extends everywhere life exists, from the deepest ocean trench to the tallest mountain.

NASA Goddard Space Flight Center (NASA-GSFC)

Ecologists make observations, ask questions and collect data.

The study of ecology begins with close observation of nature. Something catches an ecologist's eye and causes her to ask a question. Based on her observations, she then develops a best guess or **hypothesis** to answer this question. To test her hypothesis, the ecologist collects data using observations, experiments, models or a combination of the three. She then analyzes and interprets the data (often using mathematics and statistics) to see if it supports or disproves her hypothesis. This usually leads to more questions, and the process starts again. To see this process in action, let's take a look at a real-life ecological study.

In the early 1980s, ecologists began observing a sharp decline in populations of birds nesting in large tracts of forest. From previous studies, most ecologists believed the decline was connected to habitat fragmentation. Habitat fragmentation occurs when large, continuous blocks of habitat are broken up into smaller portions when land is cleared to build roads, subdivisions or crop fields. John Faaborg and Rick Clawson, two ecologists in Missouri, noticed that large forests in the Ozarks were being fragmented when trees were cut for timber. These observations led them to ask the question: *Are forest birds affected by timber harvests?*

Faaborg and Clawson hypothesized that if timber was harvested, forest bird populations would decrease. Like most hypotheses, their hypothesis contained an independent and dependent variable. An **independent variable** is changed or manipulated in some way. A **dependent variable** reacts to changes made to the independent variable. For Faaborg and Clawson, their independent variable would be whether or not trees were cut; their dependent variable would be how forest bird numbers changed in relation to the presence or absence of timber harvest.

To test their hypothesis, the ecologists designed an experiment. They picked a large forest in the Ozarks to study. They cut trees in some areas of the forest. This formed the **experimental group** of their study. They left other areas of the forest uncut. These areas formed the **control group** of their study *(Figure 1.2)*. Having both experimental and control groups allowed Faaborg and Clawson to see how forest birds reacted when trees were cut and compare this to how birds reacted in areas of the forest that were unchanged.

Because they could not collect data on every bird species that nests in the Ozarks, Faaborg and Clawson focused on five forest birds and six birds that use brushy fields. Before the trees were cut, they collected data on the population size and nesting

Researchers collect data to test whether forest birds are affected by timber harvests. Trees in the foreground have been cut recently and are starting to regrow. Larger trees in the background were left uncut.

Look for the *Ecology in Action* sections in this book to learn how resource managers use principles of ecology to keep Missouri's ecosystems healthy.

Resource Management

A forester hikes up a hillside covered with oaks and hickories, pausing every so often to spray dots of orange paint on the trunks of selected trees. The painted trees will be cut down, hauled to a lumber mill, and used to make an array of products, such as boards and furniture. By harvesting different parts of the forest at different times, the forester maintains a patchwork of trees at different stages of growth. This provides habitat for a variety of wildlife and ensures that there are always younger trees to replace those that are cut.

Insects hum as a wetland manager raises the gate on a water-control structure, letting cool water splash into a field of smartweed and sedges. In a few days, the field will have a sheen of water over it, providing a much-needed pit stop for an array of southbound waterfowl and spawning grounds for a variety of fish. After next spring's northward migration, the manager will drain water slowly off the pool, fostering a surge of lush plant growth. By mimicking the wetland's natural ebb and flow, the manager keeps the wetland ecosystem healthy.

In the middle of a boat in the middle of a lake, a generator rumbles in the still night air, zapping the surrounding water with electricity. The electricity temporarily stuns a fish that floats to the surface where it is scooped up by a biologist with a long-handled net. She records a few measurements, then slips the fish unharmed back into the water. The biologist works through the night, netting and measuring hundreds of fish. The data she collects will help her adjust the lake's fishing regulations to ensure its bass, bluegill and catfish populations remain healthy.


Resource managers apply principles of ecology to keep ecosystems healthy.

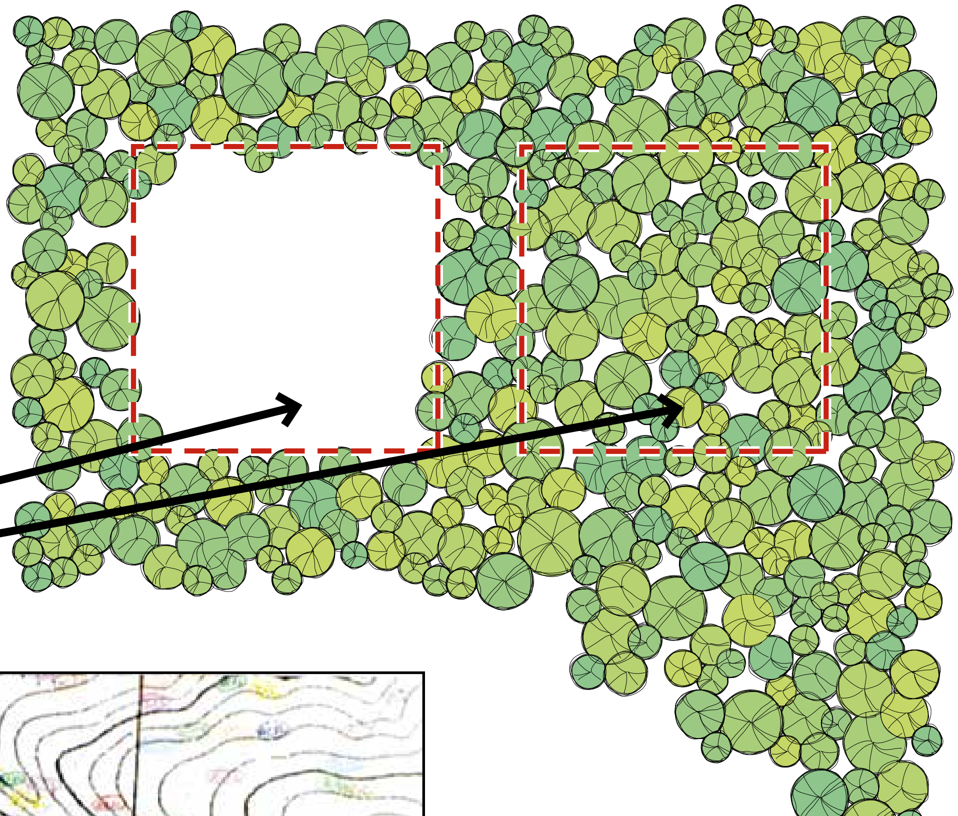
These people have something in common. Each is a **natural resource manager**, a trained professional who works to protect, maintain and restore healthy ecosystems. Foresters, wildlife managers, fisheries biologists and conservation agents are a few of the many different kinds of resource managers. All resource managers strive to balance the needs of human societies with the ability of ecosystems to produce and sustain healthy plant and animal populations. Resource managers work for federal or state agencies, nonprofit groups and private companies. Many jobs in resource management require a bachelor's degree in forestry, fisheries and wildlife, natural resources, ecology or biology. People who work in resource management enjoy working outside, are curious about how nature works, and have a passion for keeping ecosystems healthy.

Although ecology and resource management are related, they are not the same. Ecology is a pure science; resource management is an applied science. In the same way that medical doctors apply knowledge learned from anatomy and physiology to maintain and restore the health of their patients, resource managers apply principles learned from ecology to protect, maintain and restore healthy ecosystems.

success of these 11 birds. After the experimental group was cut, they collected the same data again to see if there was a change.

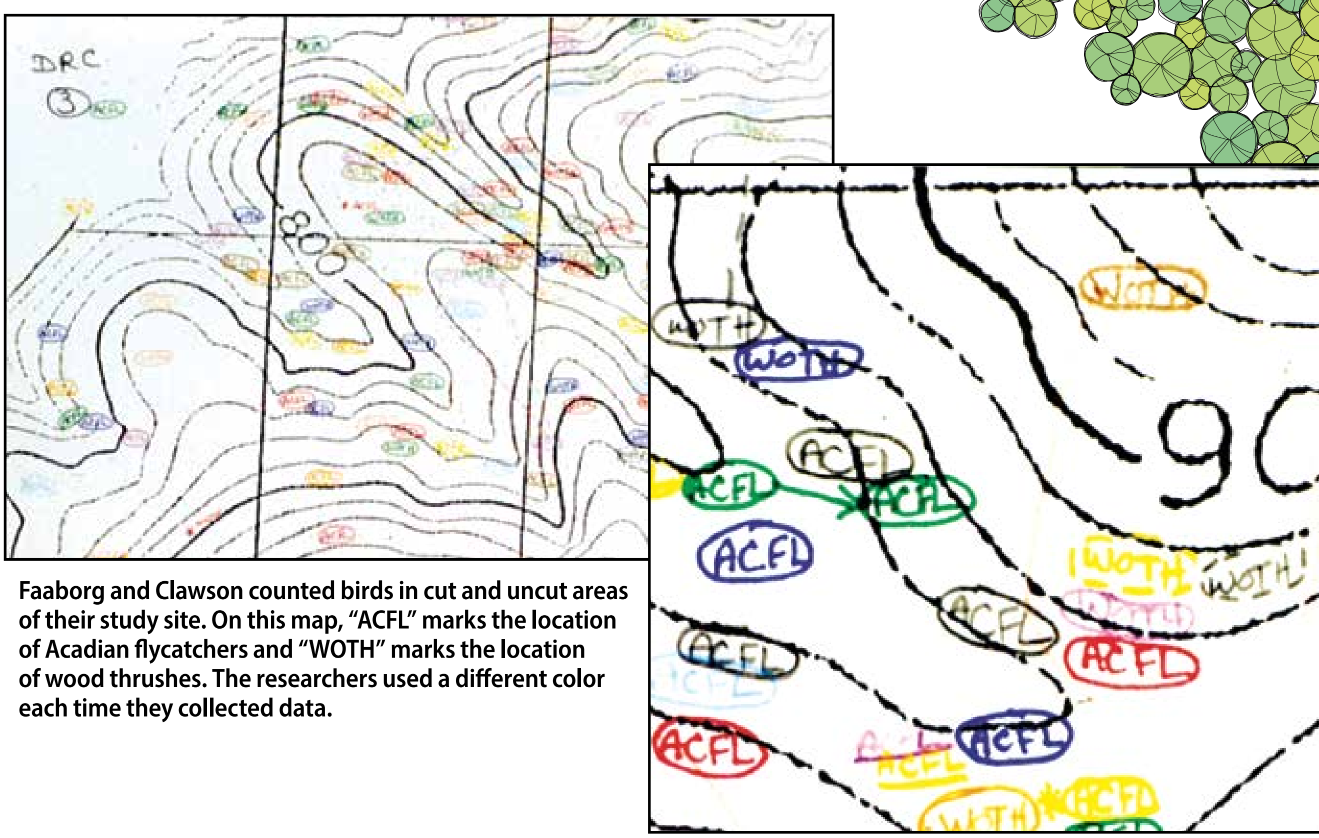
Using mathematics and statistics to analyze the data, Faaborg and Clawson learned a number of things. As expected, there wasn't a change in the way birds used the uncut forest. However, they did find that timber harvest caused the numbers of all five forest birds to drop. They also found that timber harvest caused the numbers of brushy-habitat birds to increase. This led the ecologists to ask new questions, which are still being researched.

Figure 1.2—Faaborg and Clawson set up their experiment by cutting trees in some areas of the forest and leaving other areas uncut. Areas where trees were cut formed the experimental group of their study. Uncut areas formed the control group. By comparing data collected from the control and experimental groups, Faaborg and Clawson could see how birds were affected by timber harvests.



Experimental group

Control group



Faaborg and Clawson counted birds in cut and uncut areas of their study site. On this map, "ACFL" marks the location of Acadian flycatchers and "WOTH" marks the location of wood thrushes. The researchers used a different color each time they collected data.

Conservation

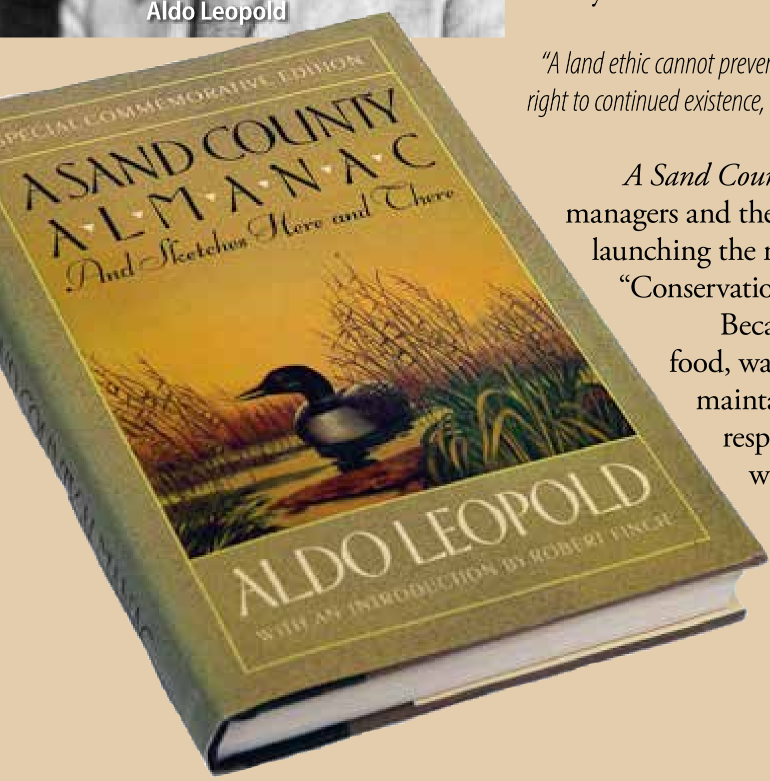
Conservation is a way of using resources that keeps ecosystems healthy and intact for use by future generations. Although conservation forms the philosophy of today's resource managers, it wasn't always so. In the early days of our country, forests were so vast and animals so abundant that no one thought they would ever disappear. Thousands of acres of trees were logged, wagonloads of animals killed, and no one thought about how these wasteful actions would affect the future. When resources were used up, people just moved on to the next patch of wilderness.

In 1905, President Theodore Roosevelt appointed Gifford Pinchot to serve as the first chief of the U.S. Forest Service. Roosevelt and Pinchot had observed the reckless abuse of America's soil, water, plants and animals. They predicted that unless these resources were used wisely, America would fail to meet its future economic and ecological needs. After taking his Forest Service post, Pinchot put into practice the idea that forests could be used to produce timber, yet maintained for the benefit of future generations. He said the goal of conservation should be "the use of natural resources for the greatest good of the greatest number for the longest time."


Aldo Leopold

Pinchot later founded Yale University's School of Forestry and served as a professor there. One of his students, a young man named Aldo Leopold, became a remarkable conservationist himself. After working for the Forest Service, Leopold was hired by the University of Wisconsin to teach courses in wildlife management. While there, he wrote *A Sand County Almanac*. In this book, he laid out what he called a "land ethic." Ethics guide how people treat each other. Leopold expanded this definition to include how people should treat the land and its natural resources. While recognizing that people need to make a living from the land, Leopold argued that economic well-being depended upon healthy ecosystems. He wrote:

"A land ethic cannot prevent the alteration, management, and use of resources, but it does affirm their right to continued existence, and, at least in spots, their continued existence in a natural state."



A Sand County Almanac was an instant success with resource managers and the general public alike, and has been credited with launching the modern conservation movement. Leopold said, "Conservation is a state of harmony between men and land."

Because we all depend upon the Earth's ecosystems for food, water, clothing and shelter, it's important to realize that maintaining the harmony between people and land is a responsibility for all of us. Learning about ecology is one way you can gain the knowledge to make wise decisions about how you use natural resources.

This view of Earth taken during the Apollo 8 space mission (1968) shows how isolated our tiny blue planet is. Ecology helps us understand how to maintain the life support systems of "spaceship" Earth.

NASA

Understanding ecology is important for many reasons.

Picture yourself cruising the galaxy in a spaceship. As you go about your day-to-day tasks, you barely notice the spaceship's life-support system working in the background. It recycles air you exhale so you always have oxygen to breathe. It cleans water you excrete so you always have enough to drink. Shields protect you from the radiation of stars. Heating and cooling systems maintain a perfect 24 degrees C climate. You even have a small garden that provides enough food for you to eat. If you were on such a spaceship, you'd want to know how every part of this life-support system worked. That way, if some part of the spaceship broke, you could fix it. Your life would depend on this knowledge.

Now picture the Earth from space. Our planet isn't so different from the spaceship. On Earth, ecological systems provide the life-support functions performed by the machines of our imaginary spaceship. On Earth, plants take in carbon dioxide and release oxygen while animals take in oxygen and release carbon dioxide. Each is an important component of the other's life-support system. On Earth, rainfall moves from rivers to oceans to the atmosphere (and through organisms) in a global water cycle, being cleaned and filtered along the way. The ozone layer protects us from the sun's radiation, and greenhouse gases trap heat to protect us from extreme temperature fluctuations.

In addition to life-support services, ecological systems provide us with an infinite number of products. You probably recognize that food—whether it's a carrot or a Twinkie—comes from nature. Every product—lumber to build your house, gasoline to fuel your car, fibers that form your clothes—comes from nature, too. Even products you wouldn't think of as being natural, such as your MP3 player or cell phone, come from nature. Although the metals, plastics and other materials that form these products may have been created in a laboratory, the raw materials came from the Earth.

If the Earth's life-support systems break down, we need to know how to fix them. Our life depends on it. That's why understanding ecology is important. Ecology gives us a way to learn how these systems work, recognize when they are failing, and provide ideas for fixing problems. ▲

Collared lizards have adaptations that help them survive the harsh conditions of Missouri's glades. To chase down food or evade predators, these colorful reptiles can run 25 kilometers per hour.

BIG IDEAS:

- For a species to continue to exist it must reproduce.
- Organisms reproduce sexually or asexually.
- Traits are passed from parents to offspring during reproduction.
- Each type of reproduction has advantages and disadvantages.
- Environmental and genetic factors cause variation among individuals in a population.
- Populations produce more offspring than the environment can support.
- In any population, some individuals have a better chance of surviving and reproducing than others.
- Natural selection causes populations to adapt to their environment over time.
- Adaptations help an organism survive in a particular environment.

Reproduction AND ADAPTATION

Sometimes called Missouri's mini-deserts, glades are hot, rocky and dry. Organisms that live on glades have an array of special structures and behaviors—called **adaptations**—that help them survive these harsh conditions. For example, prickly pears, a kind of cactus found on Missouri's glades, have dense mats of roots that soak up the tiniest amount of rain. They also have spongelike tissues in their stems that store excess water. You can tell whether it has rained recently on a glade by the shape of the prickly pears you find. After a rain, prickly pears swell up like balloons; during droughts, they deflate and wrinkle.

Water isn't the only resource in short supply on a glade. Food also is hard to find. To catch grasshoppers and other animals, collared lizards can run at speeds up to 25 kilometers per hour. During really fast sprints, these lizards run upright on their hind legs, using their long tails for balance. This allows them to take strides up to three times longer than their body length. Not only is this speed a helpful adaptation for catching prey, it also helps collared lizards avoid becoming prey themselves.

Lichen grasshoppers aren't particularly fast, but they do have a useful adaptation—camouflage—that helps them avoid becoming lizard food. These small grasshoppers are the same color as the lichen-covered rocks on which they live and have light and dark bands that disguise the outline of their bodies. When lichen grasshoppers remain motionless, they are nearly invisible to collared lizards, roadrunners and other predators hoping to eat them.

Whether to gather water, catch food or avoid being eaten, each of these traits can be thought of as a way to survive some environmental challenge. The organisms involved, however, didn't one day decide to grow more roots, run faster or change their color. Each of these traits took time to come about. The purpose of this chapter is to explain how over time, reproduction and natural selection bring about adaptations such as these.

For a species to continue to exist, it must reproduce.

Along with growth and survival, reproduction is one of the primary things that organisms do. **Reproduction** is the process by which new organisms are produced from existing organisms. Each prickly pear, lichen grasshopper and collared lizard—indeed every organism—exists as a result of reproduction.

Getting struck by a car is one of many ways turtles can die. Without reproduction to offset deaths, the turtle population would dwindle away to nothing.

Reproduction is not essential to the survival of individual organisms. Reproduction is essential, however, to the survival of each population and the species as a whole. Why? Because nature is a tough place to live! No matter how well-adapted an organism is to its environment, it eventually gets eaten, starves, catches a disease, succumbs to drought, drowns, freezes, gets struck by lightning, hit by a car, poisoned, or just wears out. Organisms die from many different causes. (Contrary to popular belief, no organism has ever died of boredom in an ecology class.) If individual organisms did not reproduce, the population—and the species—would eventually dwindle to nothing. Reproduction is essential for populations and species to continue to exist.

Giving Bobwhite Reproduction a Boost

No animal illustrates the importance of reproduction better than bobwhite quail. This little brown bird leads a tough life. Many animals eat quail or their eggs, including raccoons, skunks, domestic cats, crows, hawks, snakes and even ants. During severe winters, quail are often found frozen to death in snowdrifts or entombed in layers of ice and sleet. Hail storms, heat waves and floods also take their toll. Quail can perish from food shortages, disease, parasites, hunting, collisions with vehicles and decapitations from mower blades. On average, 90 percent of Missouri's quail die each year.

How do quail populations recover from such staggering losses? One word: reproduction. During the breeding season, quail can increase their numbers 160 percent on average and more than 300 percent in some cases. They achieve high reproduction in a variety of ways:

- Hens lay large clutches of 10 to 20 eggs.
- Quail are persistent re-nesters. When their first nest is lost to predators or weather, hens attempt to nest a second or even third time.
- Hens are promiscuous. While their mate incubates the nest, females go away to breed with a second male and lay another clutch of eggs.
- Quail often renest after successfully raising their first clutch of chicks.
- Bobwhite chicks are precocial, which means they can run, feed and take care of themselves shortly after hatching. This allows the parents to abandon their broods after a few weeks and go back to reproducing.

Organisms reproduce sexually or asexually.


Prickly pears use flowers to reproduce sexually. Like most plants, they also can reproduce asexually.

Reproduction can occur in two basic ways: asexually or sexually. In **asexual reproduction**, it takes only one parent to produce a new organism. In **sexual reproduction**, it takes two.

Asexual reproduction has many different forms *(Figure 2.1)*. For many unicellular organisms, such as bacteria and protists, asexual reproduction occurs through **binary fission**. During binary fission, a single cell divides into two separate cells, each a separate organism. Other organisms, such as hydras, reproduce asexually by **budding**. Budding occurs when a mass of cells—the bud—begins growing on the parent's body. When the bud has grown large enough, it breaks off of the parent, forming a new organism. Some organisms—including many insects and some fish, amphibians and reptiles—reproduce asexually through **parthenogenesis**. Meaning "virgin birth," parthenogenesis occurs when eggs from a female develop into offspring without being fertilized by a male. **Vegetative reproduction** is the way many plants reproduce asexually. This occurs when some part of the plant, such as its leaves, roots or stem, breaks off and begins growing into a separate organism.

Many multicellular organisms can reproduce both asexually and sexually. For example, most plants are capable of reproducing both asexually and sexually. Prickly pears undergo vegetative reproduction when

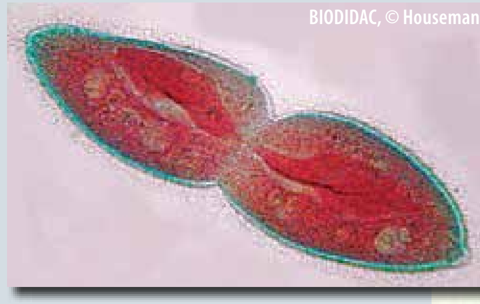

Bobwhite quail combat staggering death rates with high reproduction rates.

A bobwhite's ability to breed its way back from oblivion has important implications for resource managers. Quail are a game bird, harvested by hunters for food and sport. Managers regulate **bag limits** (the number of quail that can be harvested by a single hunter daily), what time of year hunting season occurs and how long hunting season lasts. In setting these regulations, managers take into account how many birds they predict will be shot by hunters and how many will die of natural causes. As long as hunters leave enough quail to reproduce, the population can recover the following breeding season.

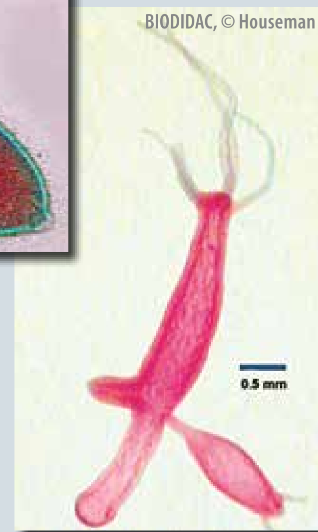
Quail numbers have dropped in recent decades not because of hunting but because of habitat loss. Quail survive best in habitat that includes a mixture of shrubs, clumpy grasses, wildflowers, annual weeds and bare soil. This diversity of plants provides everything quail need to escape from predators, find food, build nests and raise their young. To provide this kind of habitat, managers might replant an overgrown pasture to native grasses and wildflowers, disk strips through a shrubby field to create bare ground and encourage the growth of annual weeds, or set a prairie on fire to stall the growth of trees. By creating more habitat and regulating hunting, managers are working to ensure quail can continue to do what quail do best: make more quail.

their fleshy stems (called pads) break off, take root and begin growing as a separate cactus. Prickly pears also can reproduce sexually. This occurs when the flower (containing eggs) of one prickly pear is fertilized with pollen (containing sperm) from a different prickly pear. Once fertilized, the flower produces seeds that can grow into new plants. In addition to plants, many insects and some fish, amphibians and reptiles can reproduce both asexually and sexually. With extremely rare exceptions, all birds and mammals reproduce only sexually.

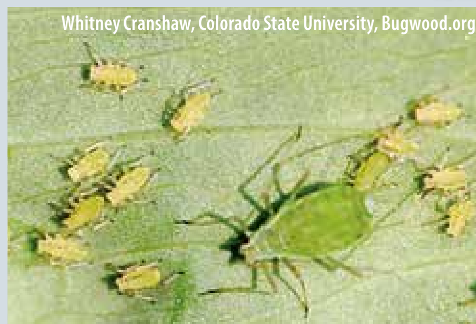
Figure 2.1—Types of asexual reproduction



▲ **Binary fission** occurs when a single-celled organism, such as this bacteria, divides into two separate organisms.



In a process called **budding**, the mass of cells growing on the lower right of this hydra eventually will break off to form a new organism. ▶



▲ Through **parthenogenesis**, this female aphid produced offspring without being fertilized by a male.

When part of a strawberry plant breaks off and develops into a separate plant (like in the lower right of this photo), it is called **vegetative reproduction.** ▶

Traits are passed from parents to offspring during reproduction.

Before either type of reproduction occurs, parent organisms make a copy of their DNA. Think of DNA as the blueprint used to build a new organism. Within this blueprint are sections of DNA called **genes** that give instructions to create specific traits. Every organism has many genes for many different traits. For example, you have genes for the number of eyes you have, your hair color, blood type and whether or not you have a widow's peak. Where did you get these genes? From your parents, of course. They were passed on to you as a result of reproduction.

In asexual reproduction, a single parent passes on an exact copy of its genes to its offspring. Unless a mistake is made when the DNA is copied, the offspring are identical copies—clones—of their parents. A prickly pear made from asexual reproduction will have the exact same genetic blueprint as its parent. If every environmental factor—amount of sunlight, water and nutrients—is the same for both parent and offspring, the two also will have the same set of traits and look identical.

Offspring created by sexual reproduction have two versions of every gene: one from the mother and one from the father. How the two versions of each gene interact with each other determines the offspring's traits. Sometimes one version of a gene masks the properties of the other. When this happens, we say that one gene is dominant and the other is recessive. If your mom gives you the gene for a widow's peak, you'll have one, even if your dad gives you the gene for a straight hairline. The widow's peak gene is dominant over the straight hairline gene. In other cases, the two versions of each gene or a combination of several different genes will influence a particular trait. The color of your eyes is influenced by several different genes. Regardless of whether you are blue-eyed and widow-peaked or brown-eyed and straight-hairlined, these genetic traits were passed on to you from your parents.

Some traits, however, didn't come from your parents. Your ability to sink a three-pointer, speak pig-Latin or drive a car weren't inherited from your parents. Although you may have been genetically predisposed to be

a great basketball player, your ability to make a jump-shot is something you learned on your own. Only traits with a genetic basis can be passed from parents to offspring. This is true of all organisms.

Each type of reproduction has advantages and disadvantages.

Sexual reproduction is complicated and risky, but ecologists believe it has a big payoff that compensates for its many disadvantages. Table 2.1 compares asexual and sexual reproduction.

One disadvantage with sexual reproduction is that males are needed. Males use resources like food, water and space that could be used by females and their offspring. Males can't produce offspring—all they produce is sperm. To produce sperm and eggs most organisms must form and maintain reproductive organs, which takes energy and resources away from other things, such as growth and survival. For sperm and egg to meet, males and females have to find each other, a pollinator has to help or the organisms involved must rely on wind or water to bring their sex cells together—none of which are foolproof systems. For many organisms, mating is a major production involving elaborate courtship rituals, brightly colored flowers or plumage, or fighting between males (and sometimes females) for mates. These displays and conflicts expose organisms to predators, injury and other risks.

Since asexual reproduction involves only one parent, asexual organisms avoid these costs. Because it requires considerably less energy, asexual reproduction can occur quickly. Bacteria can reproduce every couple of hours, enabling a few bacteria to multiply to millions literally overnight. (Remember this next time you eat a

Table 2.1—A comparison of asexual and sexual reproduction

	ASEXUAL	SEXUAL
Number of parents needed	1	2
Forms	Binary fission Budding Parthenogenesis Vegetative reproduction	Sex
Organisms that use this type of reproduction	Single-celled organisms such as bacteria and protists Most plants and fungi Many simple animals such as hydras, corals and bryozoans Some insects, fish, amphibians and reptiles	Most plants and fungi Most fish, amphibians and reptiles Birds and mammals
Are offspring genetically different from their parents?	Rarely	Always
Cause of genetic variation	Mutation	Recombination of genes during meiosis Mixing of genes from two parents during fertilization Mutation
Advantages	Requires less energy Can produce offspring at a fast rate Offspring can colonize new habitats quickly Offspring can take advantage of temporary resources	Offspring are genetically different than their parents Genetic variation helps some offspring survive when environmental conditions change
Disadvantages	Offspring are identical to their parents Many offspring die when environmental conditions change	Must have males Eggs and sperm must meet Forming reproductive organs uses energy Courtship uses energy and exposes organisms to injury and predators

Mead's Milkweed

A scorching sun beats down on a line of biologists trudging slowly across Paintbrush Prairie near Sedalia. The biologists keep their eyes on the ground, searching amidst the vegetation for Mead's milkweed, one of Missouri's rarest plants. Trying to find the little green plant with green flowers in a field of green grass is like trying to find a needle in a haystack. To better the odds, the biologists are tied together, 2 meters apart along a 30-meter rope. This keeps the researchers evenly spaced in a line and helps them track how much area they have surveyed.

Mead's milkweed provides a good example of the importance of sexual reproduction to the long-term survival of a species. Like several other milkweed species, Mead's is **self-incompatible**, which means it produces seeds only when pollen from one plant reaches the flowers of a different plant. For managers hoping to increase its numbers, this finicky reproductive habit poses a challenge.

Biologists search Paintbrush Prairie for Mead's milkweed, one of Missouri's rarest plants.

Mead's milkweed once flourished throughout Missouri's tallgrass prairies. Today, with 99 percent of our prairies gone, it hangs on in just a few small and isolated populations scattered across the state. Many populations grow on prairies grazed by cattle or mowed for hay in mid-summer, right about the time Mead's milkweed begins producing flowers. Without flowers to make pollen, sexual reproduction has stopped in many populations. In a 2005 survey, biologists found 212 Mead's milkweed stems across the state, but only five seed pods. Without seeds, Mead's milkweed spreads by sprouting new stems from a long underground rhizome. Although they look like different plants, each of these stems is actually part of the same plant, and, therefore, genetically identical.

This loss of genetic diversity worries resource managers. With few seeds to colonize new prairies, Mead's milkweed populations have little chance of expanding beyond their current locations. With less genetic diversity, adaptation has a harder time keeping up with drastic environmental changes, and small, isolated Mead's milkweed populations are prone to being wiped out. To prevent this, resource managers are trying a number of approaches, including:

- Encouraging landowners with Mead's milkweed to delay grazing and haying until mid-September, after Mead's milkweed has dispersed its seeds
- Asking landowners to avoid spraying pesticides, which kill bees, a primary pollinator of Mead's milkweed
- Reducing herbicide use in areas where Mead's milkweed occurs
- Using prescribed fire to stimulate the growth of Mead's milkweed.

In addition, at Wah'Kon-Tah Prairie in southwestern Missouri, managers have planted over 150 Mead's milkweed plants obtained from botanical gardens. The managers hope the new plants will cross-pollinate with the prairie's naturally growing population and produce seed that can be used to start additional, genetically diverse populations.

Will these actions be enough to prevent Mead's milkweed from vanishing from Missouri's prairies? Back at Paintbrush Prairie, the biologists have finished their survey. After searching all day, they found 61 Mead's milkweed plants. Only three had flowers. Three, however, is better than none.

doughnut dropped on the floor. The five-second rule doesn't work!) Reproducing at a faster rate allows asexual organisms to take advantage of temporary resources and colonize new habitats. A big disadvantage of asexual reproduction is that offspring are usually identical to their parents. This makes it tough for asexual organisms to adapt to changing environments.

The big payoff for sexual reproduction is that mixing genes from two parents produces offspring with unique genetic blueprints. Unique genetic blueprints leads to offspring with unique traits. Populations with individuals having unique traits are more likely to survive if environmental conditions change. If all the members of the population had similar genes and traits, the population would be less likely to survive a disease outbreak or a change to its habitat. **Genetic homogeneity**—when all the members of a population have similar genetic blueprints—can cause extinction. Variation among members in a population is key to survival.

Environmental and genetic factors cause variation among the collared lizards in a population.

Environmental and genetic factors cause variation among individuals in a population.

For nearly any trait we can measure, some variation exists among the individuals making up a population. For example, if we were to catch all the 12-month-old collared lizards in a glade and measure their lengths from their snouts to the tips of their tails, we would find that some lizards are shorter and some longer than others. Likewise, if we measured the heights of prickly pears in a glade—or even the heights of all the students in your class—we would find a range of sizes. What causes this variation?

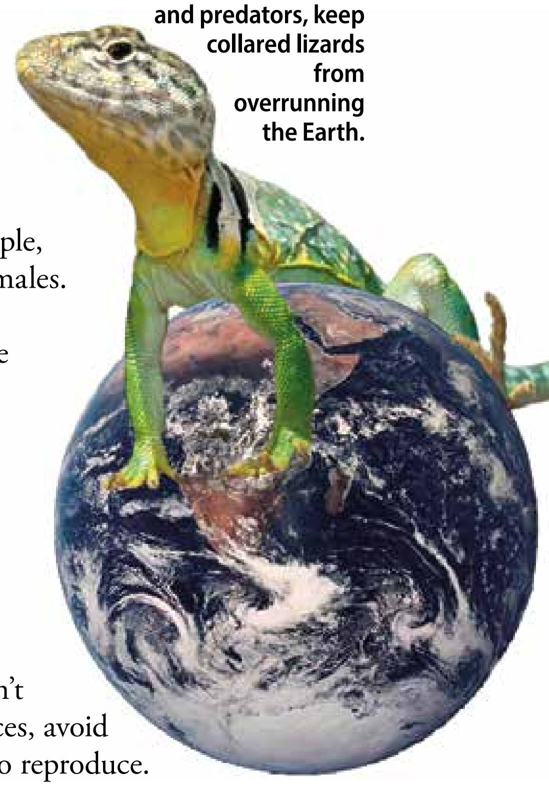
Some variation is caused by environmental factors. Some of the collared lizards we are studying may live where food is more abundant. With more to eat, these lizards might grow longer than their cousins who live where food is scarce. Some prickly pears may be bigger because they live in a sunnier or wetter location than other prickly pears.

Some of this variation is caused by genetic factors. The genetic blueprint used to build you is different from the blueprint used to build your best friend. In fact, none of the blueprints for anyone in your class is exactly alike. Each individual's DNA is unique. Two things cause this: mutations and the recombination of genes during sexual reproduction.

Every cell in an organism's body contains its complete genetic blueprint. Each time a cell divides, the parent cell makes a copy of its DNA to pass on to the new cell. A **mutation** occurs when a mistake is made during the copying, resulting in a genetic blueprint different from the original. Sometimes mutations cause the new cell to die. Sometimes mutations don't affect the new cell at all. And, sometimes mutations cause the new cell to have traits different from its parent. In unicellular organisms, like bacteria, cell division is a form of reproduction. For bacteria and other asexually reproducing organisms, mutations are the principal cause of genetic variation for the population. Mutations also can cause variation in sexually reproducing populations if the mutation occurs during the formation of sex cells. When an egg or sperm with a mutation combines with its counterpart, the mutation can affect the traits of the offspring.

Another cause of genetic variation occurs only in sexually reproducing populations. **Recombination** occurs during the formation of eggs and sperm when homologous chromosomes trade genetic information with each other. This causes the eggs or sperm to have a genetic blueprint different from the genetic blueprint

of the parent. Genes are mixed and shuffled a second time when a sperm fertilizes an egg to form a new organism. This twofold shuffling and mixing of genetic information creates variation in sexually reproducing populations.



Environmental factors, such as food shortages and predators, keep collared lizards from overrunning the Earth.

Populations produce more offspring than the environment can support.

With abundant resources, populations can grow at startling rates. For example, imagine we have a population of 10 collared lizards—five males and five females. If we made sure that everything our lizards needed was in plentiful supply, within five years the population would increase to 2,500 lizards. Somewhere between years seven and eight the population would climb above 100,000 lizards. And, after just a decade of lizard-farming, our population would contain 2.5 million individuals! Left unchecked, our collared lizards would quickly overrun the earth, end civilization as we know it and generate a series of low-budget horror movies on the science fiction channel.

Of course this could not happen. Many factors would keep our lizard population—or any population—in check. Resources are rarely abundant, predators are often hungry, and the environment is harsh and unforgiving. Although populations produce many offspring, the environment usually can't support them all. Individuals with traits that help them compete for resources, avoid predators and survive harsh conditions are more likely to live long enough to reproduce.

Because their camouflage helps them avoid predators, lichen-colored grasshoppers have a better chance to survive and reproduce than pink-colored grasshoppers in the same environment.

In any population, some individuals have a better chance of surviving and reproducing than others.

Imagine a population of lichen grasshoppers. Some of the individuals in the population are lichen colored and other individuals are hot pink. The lichen-colored grasshoppers are more likely to avoid predators because they blend in with their environment. Because they are better at avoiding predators, more lichen-colored grasshoppers than hot-pink grasshoppers will likely survive to reproduce. When some individuals survive and reproduce at a higher rate than others in the same population, **differential reproduction** is occurring.

Differential reproduction occurs in most populations. Sometimes individuals reproduce at a higher rate because, like the lichen-colored grasshoppers, they are better able to survive in their environment. Other times, individuals reproduce at a higher rate because they are able to attract more mates. Greater prairie-chickens live on Missouri grasslands. Male prairie-chickens fight with each other and do a courtship dance to attract females. Although fighting exposes males to injury and dancing exposes them to predators, the winning fighters and best dancers attract the most mates.

Greater Prairie-Chicken Translocation

Starlight shines down on a team of Missouri biologists creeping through a prairie in Kansas. One of the biologists swings an antenna from side to side, trying to home in on a sleeping prairie-chicken. Three months earlier, several of the stocky, foot-tall hens were trapped, fitted with tiny radio transmitters and released to go about the business of mating and nesting. Now, with their chicks hatched and partially grown, the biologists have returned to catch them.

Tonight, the biologists are lucky. The antenna man points to a nearby clump of grass, and another biologist sneaks slowly forward. Suddenly, he swings a huge net down, capturing a hen and two of her chicks. They flap and struggle to get free.

In the 1860s, prairies covered nearly a third of Missouri and prairie-chickens were so abundant they were shot by the wagonload and shipped to game markets in St. Louis, Chicago and New York. Over the next half century, overharvest and loss of prairie habitat caused prairie-chicken populations to plummet. By the 1990s, 99 percent of Missouri's prairies had been plowed under and less than 500 prairie-chickens remained, scattered in small, isolated populations in the northwest and southwest corners of the state.

With such a substantial drop in numbers, Missouri's prairie-chicken population has lost genetic diversity. The potential for a **genetic bottleneck** worries conservationists. With less genetic variation to work with, adaptation cannot keep up with drastic environmental changes, and small populations are prone to extinction. In addition, breeding between closely related individuals, called **inbreeding**, often results in a decrease in reproductive fertility. For prairie-chickens, this means fewer eggs hatch. In Illinois, a prairie-chicken population of just 50 birds saw its hatching rate drop from 93 percent in the 1930s to 38 percent by 1990. Over the same period, the same population lost about one-third of its genetic diversity. Researchers think the loss of diversity and drop in hatching are connected. Surveys show that many of Missouri's prairie-chicken populations have dropped to critically low levels. Biologists in Missouri don't want the same thing to happen here.

In 2008, the Conservation Department began a prairie-chicken translocation project. **Translocation** involves taking individuals from thriving populations and releasing them into struggling populations. Over a 5-year period, managers plan to relocate up to 500 prairie-chickens from Kansas to a healthy prairie in southwest Missouri. They hope this will establish a viable flock and allow biologists to study how well the translocated birds survive and which habitats they use. If the translocation is a success, the information gained could help stop the downward spiral of prairie-chicken populations elsewhere in Missouri.

This captured prairie-chicken from Kansas will be translocated to a new home in Missouri.

Back in Kansas, the captured prairie-chickens are untangled, loaded into a pickup, and transported to Wah'Kon-Tah Prairie near El Dorado Springs, Missouri. There, the birds are placed inside a release box, and the box is deposited on a hillside covered with auburn grass and yellow wildflowers. Hiding in a blind, a biologist pulls on a rope, and the door to the box swings open. Cautiously, the hen pokes her head out. Clear blue sky stretches from horizon to horizon. Satisfied with the new surroundings, she shuffles off across the prairie, her two chicks follow, and the future of prairie-chickens in Missouri becomes three birds brighter than before.

Natural selection causes populations to adapt to their environment over time.

Let's return to our lichen grasshopper population. Because the trait for body color has a genetic basis, lichen-colored parents produce lichen-colored offspring more often than pink-colored offspring. Therefore, with each generation of grasshoppers, the trait of being lichen colored becomes more common in the population. If this process of differential reproduction and passing of traits continues over a long period of time, eventually all the grasshoppers in the population will be lichen colored *(Figure 2.2)*.

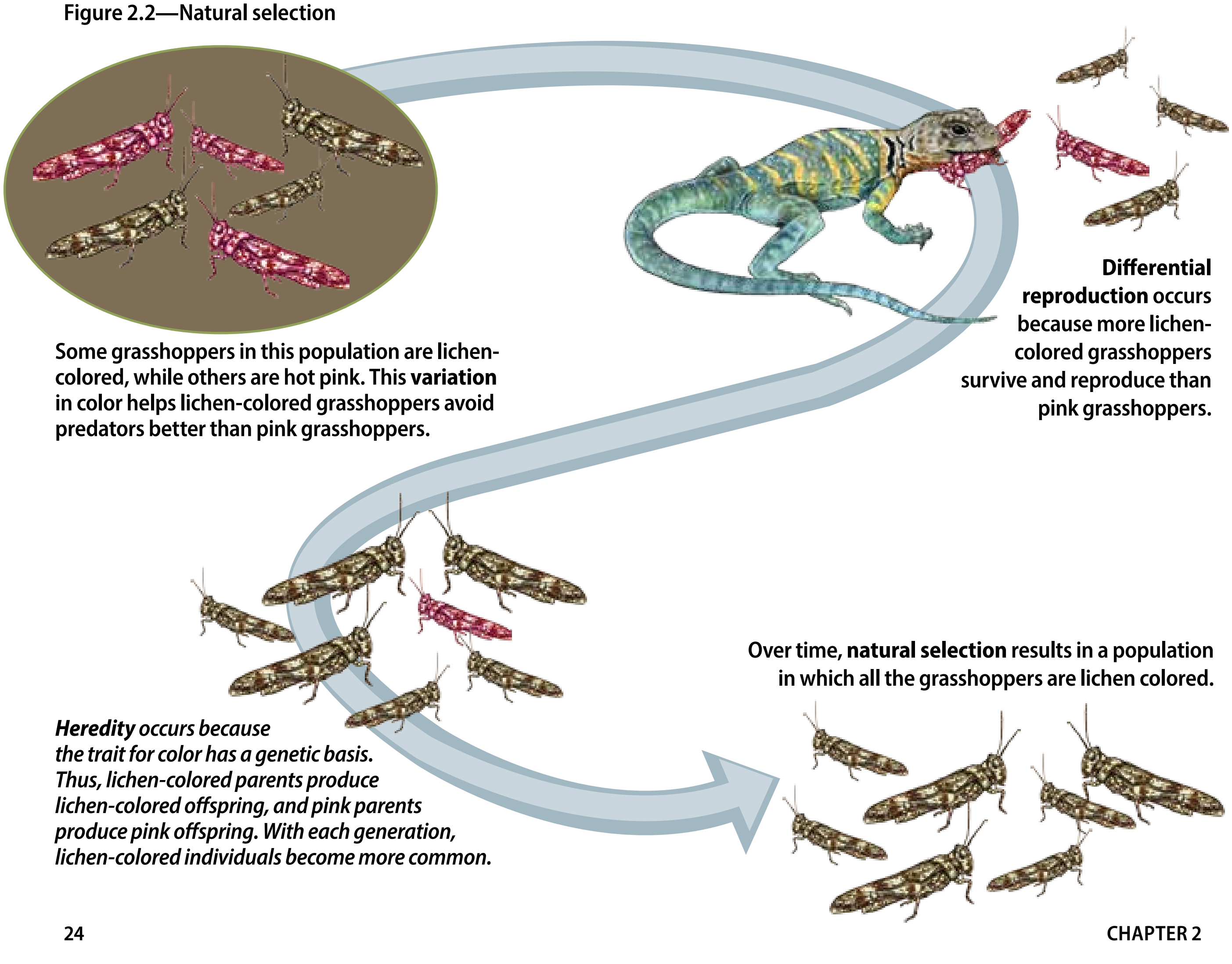
We've just described **natural selection**, the process by which populations become adapted to their environment over time. An easy way to remember how natural selection works is with an equation:

Variation + Heredity + Differential Reproduction = Natural Selection

When some individuals in a population have different traits, variation exists. If the trait has a genetic basis, it can be passed from parent to offspring, which is called **heredity**. When individuals possessing the trait survive and reproduce at a higher rate than other individuals in the population, differential reproduction is occurring. And, if all three of these things happen, natural selection will occur.

Natural selection is not a conscious process in which organisms strive to develop new traits to help them survive. A hot-pink grasshopper would probably prefer to be lichen colored, but unless he inherited the ability to change color, he's stuck being pink. Eventually, sunlight might fade the color of a hot-pink grasshopper. However, because the change was due to environmental factors and not genetics, the faded color could not be passed on to the grasshopper's offspring, and natural selection would not occur.

Figure 2.2—Natural selection



Natural selection is not a random process. Individuals with favorable traits tend to survive more often than individuals with unfavorable traits. There's nothing random about that! If natural selection were random, hot-pink grasshoppers would have just as much chance of surviving as lichen-colored ones.

Natural selection does not lead to organisms that are perfectly adapted to their environment. If that were the case, all collared lizards would be fast enough to catch enough to eat and all lichen grasshoppers would be camouflaged well enough to avoid being eaten. Of course, this isn't the case. Natural selection works because some traits are *more* favorable than others. If an organism's traits give it an advantage—or if the organism is just lucky—it will survive to reproduce and pass its traits to the next generation.

Adaptations help an organism survive in a particular environment.

Over time, natural selection produces **adaptations**. Every organism has adaptations. The gills of fish, the venom of rattlesnakes, the bitter taste of some plants—all of these are adaptations. For a trait to be an adaptation, it must help an organism survive in a particular environment. It must also be genetically based, so that the trait can be passed from parent to offspring.

Adaptations aren't just anatomical structures. Behaviors and physiological processes also can be adaptations. For example, when predators get too close to a killdeer's nest, one of the parents will act as if it has a broken wing to lure the predator away. While this behavior may seem risky for the parent, it does contribute to the survival of the population as a whole. Because of this, a killdeer's broken-wing behavior is an adaptation. During cold winters, spadefoot toads produce a compound that acts like antifreeze in their blood. This physiological adaptation helps him survive freezing temperatures.

It's important to remember that adaptations are suited to a specific environment. The same adaptation that helps an organism survive in one environment might be unfavorable to survival in a different environment. The gills of fish help them use oxygen dissolved in water, but not from air. Lichen grasshoppers blend in on a glade, but they would stick out in an environment of hot-pink rocks. ▲

An adaptation that helps an organism survive in one environment might be unfavorable in a different environment. A lichen-colored grasshopper sticks out on a pink-colored rock.

In the 1980s, the Conservation Department released river otters into rivers and wetlands throughout the state in hopes of increasing otter numbers.

BIG IDEAS:

- Ecologists measure populations in different ways.
- Births and deaths cause populations to grow and shrink.
- With abundant resources, populations can grow quickly.
- Many factors limit how large a population can grow.
- Some limiting factors affect growth regardless of the population's density; other limiting factors affect growth in relation to the population's density.
- Population growth slows as population size nears carrying capacity.

POPULATION checks AND balances

A crowd of elementary students waits along the muddy bank of a creek. A Conservation Department pickup pulls up, and two biologists get out. Wearing thick leather gloves, the biologists unload a wire cage and carry it down the bank to the water's edge. Following the advice of the biologists, teachers warn students to keep their fingers away from the cage. The kids wear t-shirts that read, "Bring 'Em Back to Missouri."

This will be the students' first glimpse of an animal long absent from Missouri—the river otter. Early in our state's history, habitat destruction and unregulated trapping nearly wiped out Missouri's otters. A 1936 survey found only a handful of otters surviving in the swamps of southeastern Missouri's Bootheel. In the early 1980s, the Conservation Department started a stocking program to restore otters to their former habitat. The otters in the cage are part of this program.

When the otters poke their whiskered faces out of the cage, the children cheer. Giving little grunts and chuckles, the otters slip out and shuffle toward the creek. Hunch-backed and clumsy-looking on land, once they hit water they move with the sinuous grace of ballet dancers. For a few minutes the otters put on a show, swimming and diving exuberantly, obviously happy to be free of the cage. Then, one-by-one, the otters submerge and disappear, leaving a trail of bubbles in their wake.

Since those first releases in the 1980s, Missouri's otter population has soared from 70 to more than 15,000. River otters now flourish in nearly every aquatic nook and cranny of the state. Otters have made their way to places ecologists never imaged they could—sometimes to places where they aren't wanted. Otters eat fish. Fifteen-thousand otters eat tons of fish. This has caused conflicts between anglers and the newly established otter populations.

How did Missouri go from otterless to otterful in such a short time? What can be done to curb the growth of Missouri's otter population? In this chapter we'll learn how ecologists study populations, explore how populations grow, and examine the factors that limit population size.

Ecologists measure populations in different ways.

Recall from Chapter 1 that a population is a group of the same species living together in the same place at the same time. The boundaries of a population can be defined by the species' geographic range, by a natural barrier, such as a mountain range, or by an artificial barrier, such as the boundaries of a conservation area, set up by an ecologist studying the population *(Figure 3.1)*. We might study a population of otters living in the Grand River or a population of termites living in a rotting log.

Several things link members of a population to each other. Individuals in a population rely on the same resources for energy, water, shelter and space. They interact with each other on a regular basis. Most importantly for population growth, members of a population can mate with each other and produce offspring.

Understanding populations is important for many reasons. Ecologists study populations to:

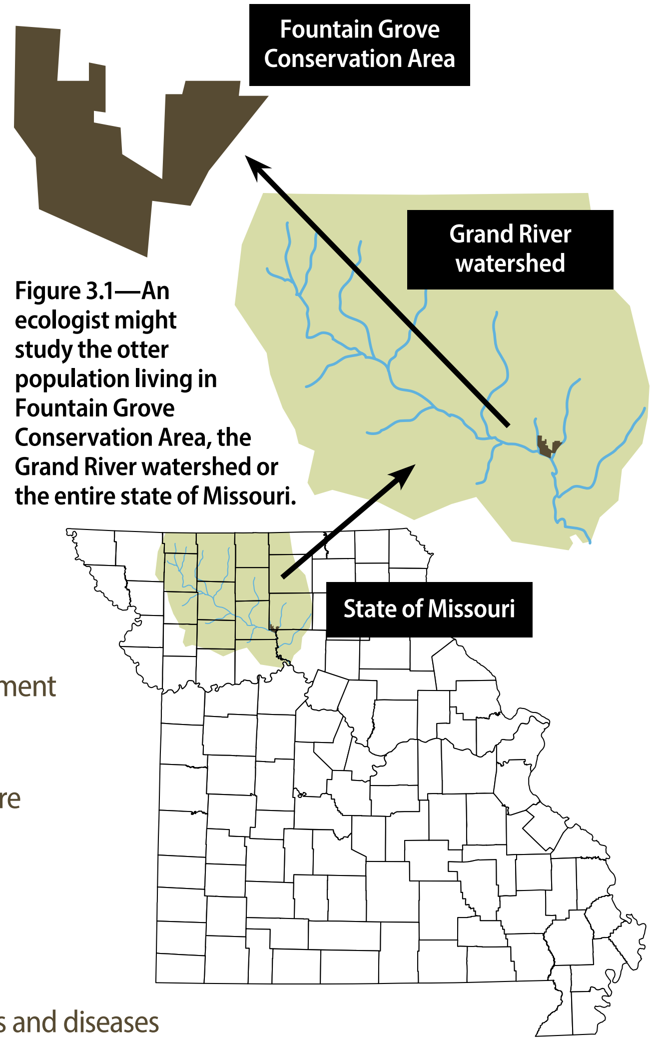


Figure 3.1—An ecologist might study the otter population living in Fountain Grove Conservation Area, the Grand River watershed or the entire state of Missouri.

- Predict how a population might react to a change in its environment
- Understand what causes a population to grow or shrink
- Figure out how much space a population needs to stay healthy
- Predict how many individuals to release into a new area to ensure the population persists
- Determine what kinds of resources could save an endangered species from extinction
- Decide how many individuals could be harvested from a game population without causing it to decline
- Learn how to control populations of crop pests, weeds, parasites and diseases

When you go to the doctor, a nurse records your temperature, blood pressure, pulse and weight. These measurements—called vital signs—give the doctor clues to your overall health and how your body is functioning. In a similar fashion, ecologists learn a lot about a population by gathering a few key measurements.

One of those measurements is **population size**, or the total number of individuals making up the population. Ecologists usually represent population size with an uppercase N. N = 200 means that the population consists of 200 individuals. Population size rarely stays the same for long. Usually, it fluctuates as individuals die of old age, get eaten by predators, give birth to offspring or migrate into or out of the population.

Another important measurement is population density. **Population density** is the number of individuals per unit of area. To calculate density, you divide a population's size by the area it occupies. One river otter per square kilometer, 200 white oaks per hectare and 50 termites per square meter are all examples of population density. In general, larger organisms have lower population densities. This makes sense because larger organisms usually need more space and other resources to survive. For any population, densities will be higher when resources are plentiful and lower when resources are scarce.

Dispersion describes the spacing of individuals in the population in relation to each other. Populations can be dispersed in a clumped, uniform or random pattern *(Figure 3.2)*. In clumped dispersions, individuals are grouped in tight clusters. In uniform dispersions, individuals are spaced even distances from each other. In random dispersions, individuals can be found anywhere within an area.

For many populations, the pattern of dispersion is related to the arrangement of resources in a given area. If food, nesting sites, sunlight or other resources are distributed in patches across the landscape, the population will likely have a clumped pattern of dispersion. River otters are aquatic organisms, so you would expect to

Using Mark-Recapture to Estimate Population Size

For animals that are elusive or scattered throughout an area, ecologists use **mark-recapture methods** to estimate population size. Mark-recapture involves catching a sample of the population and marking the captured individuals with paint, a leg band, an ear tag or in some other way. After being marked, the individuals are released and allowed to mix back into the population. After time has passed, a second sample of individuals is captured. By comparing the number of individuals marked in the first sample to the number that have marks in the second sample, ecologists can estimate the total population size. The **Lincoln-Petersen estimate** is a simple and widely used method of mark-recapture sampling. Here's the formula:

A researcher marks a female cardinal with a metal leg band.

$$N = \frac{n_1 n_2}{m_2}$$

N = population size
n_1 = the number of individuals marked and released in the first sample
n_2 = the total number of individuals captured in the second sample
m_2 = the number of individuals with marks in the second sample

Let's say we are trying to estimate the population size of the cockroaches living in your garage. One night we go to your garage, capture 32 roaches and paint little white marks on their backs. A week later we go back and capture 44 roaches. We note that 15 roaches in our second sample have white marks from the previous sample. Let's plug these numbers into our equation:

$$N = \frac{(32)(44)}{15} \quad \textit{becomes} \quad N = \frac{1{,}408}{15} \quad \textit{which means} \quad N = 94$$

From this calculation, we can estimate that about 94 cockroaches live in your garage. Yuck! Ecologists use the Lincoln-Petersen method to estimate the population size of everything from box turtles to bluegill to bluebirds. While it is effective, this method assumes:

- Between the two samples, the population has no births, deaths, immigration or emigration.
- All individuals have the same probability of being caught.
- Marking does not affect survival.
- Marking does not affect the likelihood that an individual will be recaptured.
- Marked individuals do not lose their marks between captures.

If any of these assumptions prove false, the accuracy of the Lincoln-Petersen estimate decreases.

find individuals in an otter population clustered near water. When resources are uniformly distributed across the landscape, the population is more likely to show a random or uniform pattern of dispersion. If growing conditions were similar throughout a prairie, you would expect to find a population of Indian grass dispersed in a uniform pattern across the landscape.

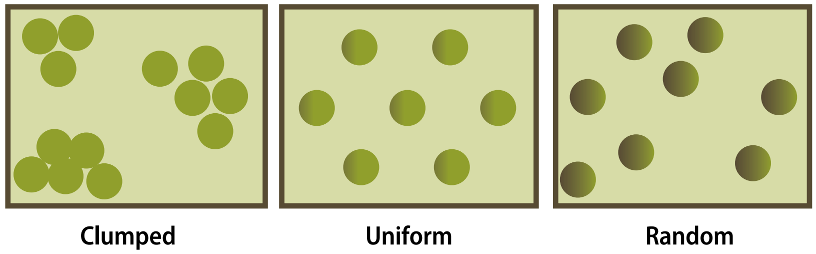


Figure 3.2—Types of Dispersion

Sampling Populations

How many otters live in a watershed? How many white oaks live in a forest? How many bluegill live in a pond? To determine population size, ecologists use censuses and samples. Some organisms are easy to count. Although it might take time, you could easily count every white oak in a 20-hectare forest. This **census**—a count of all the individuals in a population—would give you a precise measurement of that forest's white oak population.

But, what about populations scattered over an area of hundreds of square kilometers? Or populations of organisms that move around—like river otters or songbirds? What about populations that are difficult to see because they live underwater or underground, are microscopic or come out only at night? In each of these cases, ecologists use samples. In a **sample**, you count a small portion of the population and use it to estimate the entire population size. It's like guessing how many jellybeans are in a jar. If the jar is 20 centimeters tall, you might count the number of jellybeans in the first two centimeters of the jar (your sample) and multiply by 10 to estimate how many jellybeans are in the entire jar.

Samples can be obtained in many ways. Sometimes ecologists divide a large area into smaller sections called **quadrats** and count all the individuals in some of the quadrats. At other times, ecologists walk **transects**, straight lines of a known length, through an area and count the individuals they see. For elusive animals, ecologists can count nests, scat, hair or other evidence left behind. Here are a few ways Missouri ecologists obtain samples to estimate population sizes.

A hair snare snags a tuft of fur when animals brush against it.

Hair Snares for Black Bears

To figure out how many black bears live in Missouri, biologists use hair snares, a short piece of barbed wire that snags a tuft of fur when bears brush against it. By extracting DNA from the snared hair, researchers can learn the bear's sex, age and kinship to other bears. Because each bear's DNA is unique, hair samples can be used as genetic identification tags, allowing researchers to tell whether a specific sample is from a previously identified bear or a different one. This information will reveal important characteristics about Missouri's bear population, such as its size, ratio of males to females, travel patterns and genetic diversity.

The Shocking Truth About Counting Fish

Fisheries biologists sample populations using a variety of gear and techniques, few of which require SCUBA tanks and swim fins. In fact, a fisheries biologist wouldn't want to dip a single toe in the water when using

The interactions that take place among members of the population also affect dispersion. If individuals are attracted to each other, the population tends to have a clumped pattern of dispersion. In winter, bobwhite quail are attracted to each other to keep warm. Gathering in groups—called coveys—leads to quail populations having a clumped dispersion in winter. When individuals in a population are repelled by each other—like during summer when bobwhite males chase other males out of their territory—the population usually has a uniform pattern of dispersion. If individuals ignore each other, the population tends to have a random pattern of dispersion.

one of the most common sampling techniques—electrofishing. Electrofishing gear pumps electrical current into the water. This stuns nearby fish that float to the surface where biologists capture them with long dip nets. After recording information about each fish, such as its species, sex, length and weight, the fish is returned to the water unharmed. From this information, biologists learn what species of fish live in a body of water and estimate each species' population size, sex ratio and other important population characteristics.


Electrofishing is one method biologists use to sample fish populations.

The Plane Truth About Counting Ducks

Never bet against a waterfowl biologist in a game of guessing how many jelly beans are in a jar. Why? Because waterfowl biologists count thousands of ducks each fall and spring—from an airplane, 400 feet in the air, flying at 100 miles per hour. As they zip over a large concentration of ducks, the biologist divides it into smaller segments of similar densities, say a 1,000 ducks each. When the birds are spread out, it may take a fairly large area to equal 1,000 ducks. When it's cold, 1,000 ducks might be packed together in a relatively small space. The biologist then counts the total number of segments and multiplies by 1,000 to get an estimate of the total number of ducks. After estimating the total number of ducks, the biologist makes another, much lower pass in the airplane. This time, the biologist tries to figure out the percentage of mallards, pintails and other ducks making up the concentration. In this way, biologists learn how many and what kinds of ducks use Missouri's wetlands during the fall and spring migrations.


Waterfowl biologists use aircraft to count ducks and geese.

It's a Dirty Job, But Someone's Got to Do It

Scouring a river for otter scat isn't the most glamourous job in the world, but it does help biologists estimate otter numbers. Researchers are working to determine if a relationship exists between how much scat they find along a river and the number of otters that live there. If a relationship exists, biologists will have an inexpensive and easy way to estimate otter abundance. In addition, researchers are testing whether DNA can be extracted from the scat. If so, it could be used to give each otter a unique genetic identity, allowing researchers to learn about an otter population's travel patterns, sex ratio and genetic diversity.


Researchers count otter scat to estimate population size.

Births and deaths cause populations to grow and shrink.

Populations are dynamic, continually growing and shrinking over time. In 1980, we had about 70 river otters in Missouri. By 2000, the population had skyrocketed to over 15,000. In 2007, the population had decreased to about 10,000 individuals. What caused this fluctuation? The same thing that causes all populations to fluctuate over time—births, deaths, immigration and emigration *(Figure 3.3)*.

Births and **immigration** (moving into an area) add to population size. Over an 11-year period, the Conservation Department took 845 otters from the swamps of Louisiana and released them into the streams and wetlands of Missouri. This immigration of otters caused the population size to increase. Once the otters were here, they started reproducing at incredibly high rates. Although litters of two or three pups are typical in other populations, in Missouri, female otters gave birth to three or four pups each spring. The high number of births contributed to fast population growth.

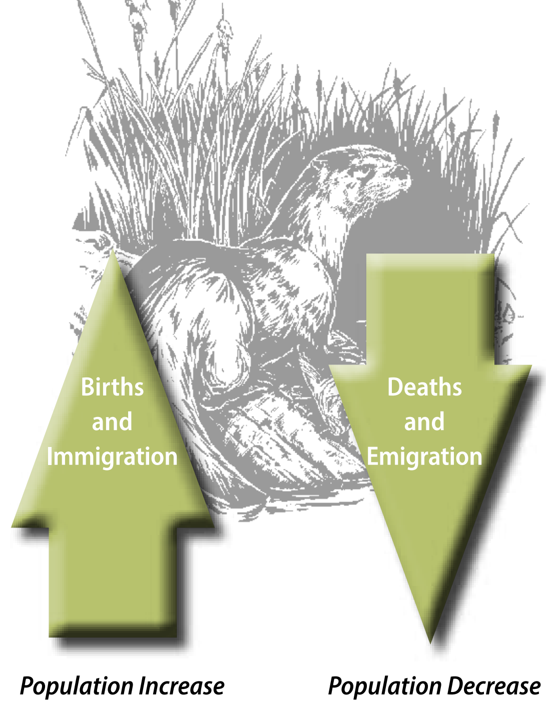


Figure 3.3—What affects population size?

Deaths and **emigration** (moving out of an area) subtract from population size. Due to an abundance of habitat and food, few otters moved out of Missouri. Because otters have few natural predators, there were also few deaths. As otters multiplied and began moving into fishing ponds and streams, phone calls from angry anglers began pouring in to Conservation Department offices. Something had to be done to put the brakes on the out-of-control otter population. In 1996, the Conservation Department started an otter-trapping season. Over the next decade, trapping helped bring Missouri's otter population down to a level that was better for fish populations and people.

For most populations, births and deaths affect population size more than immigration and emigration. When there are more total births than deaths, the population grows. And, when there are more total deaths than births, the population shrinks.

With abundant resources, populations can grow quickly.

William Shakespeare must have been a bird lover. In his plays and poems he wrote about all kinds of birds, from ravens to peacocks to nightingales. What does Shakespeare have to do with ecology? In 1890 and 1891, the American Acclimation Society, a group hoping to introduce every bird in Shakespeare's plays to the United States, released 160 European starlings into New York's Central Park. Since that time, the starling population has skyrocketed. Starlings are now one of the most abundant birds, not only in Missouri, but throughout North America. Their population of 200 million stretches from one coast to the other, each bird a direct descendent of the original 160 released in Central Park.


The European starling population grew from 160 birds to more than 200 million in just over a century.

We've seen how Missouri's otter population went from 70 to 15,000 in just a few years. We've learned how North America's starling population went from 160 to 200 million in just over a century. What does this tell us about the ability for populations to grow? It tells us that regardless of the population—whether it is starlings, otters or human beings—the pattern of growth is always the same.

With abundant resources—food, space, nesting sites—populations grow slowly at first and then faster and faster as time

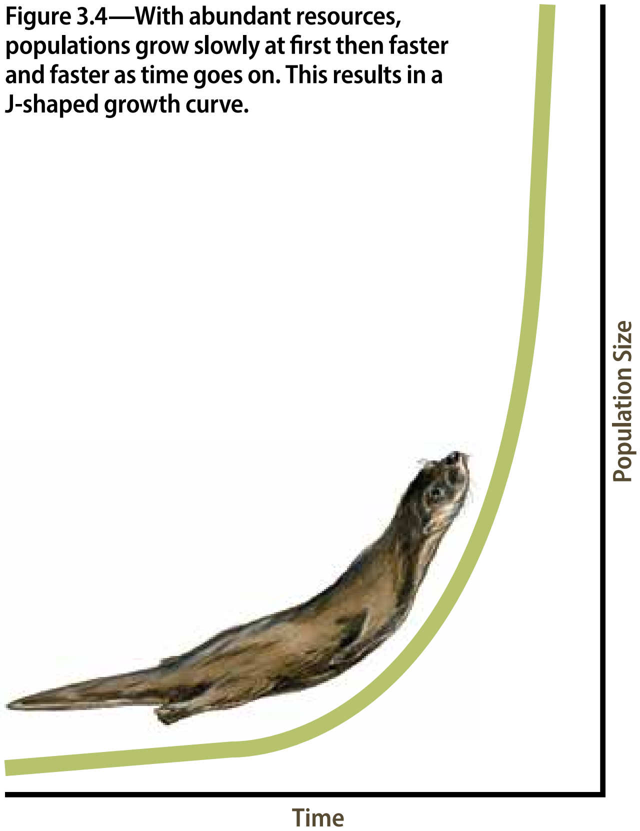


Figure 3.4—With abundant resources, populations grow slowly at first then faster and faster as time goes on. This results in a J-shaped growth curve.

goes on. If we were to use a graph to plot this kind of growth over time, it would give us a J-shaped curve like the one shown in Figure 3.4.

What causes this pattern of growth? Reproduction. Parents in each population have offspring. Eventually these offspring grow up, reach reproductive age, and have offspring themselves. This causes the population to increase by multiplication rather than addition. This type of growth, when a population increases in proportion to its size, is called **exponential growth**.

Exponential growth is characteristic of populations rebounding from a catastrophe, like a population of bass left alone after years of overfishing or a population of oak trees recovering from a wildfire. Exponential growth is also typical of populations newly introduced into a favorable environment—like Missouri's river otters, European starlings in North America or an outbreak of insect pests in your vegetable garden. Some populations, such as the human population, grow continuously because babies are added to the population at all times of the year. Other populations, such as river otters,

Additive Growth vs. Exponential Growth

To illustrate the difference between exponential growth and growth from addition, let's consider a riddle. Say I hired you to be an ecologist for the Conservation Department. I offer you two different options for getting paid. In the first option, you start off making a dollar, but I add a dollar to your salary each week. In the second option, you start off making a penny, but I double your salary each week. Which is the better offer? Let's use a table to figure it out.

Week	Salary Option 1	Salary Option 2
1	$1	1¢
2	$2	2¢
3	$3	4¢
4	$4	8¢
5	$5	16¢
6	$6	32¢
7	$7	64¢
8	$8	$1.28
9	$9	$2.56
10	$10	$5.12
11	$11	$10.24
12	$12	$20.48
13	$13	$40.96
14	$14	$81.92
15	$15	$163.84

As you probably guessed, the second offer is the better deal. This is because in the second option your salary grows by multiplication rather than addition. As you can see from the table, your salary starts off growing slowly, but quickly picks up. By the twenty-eighth week, you would be making over one million dollars! This shows the power of exponential growth.

add offspring to the population at certain times of the year, usually when resources are most abundant. Regardless of whether the growth is continuous or in spurts, with abundant resources, all populations have the capability to grow exponentially.

To figure out how quickly a population might grow over time, ecologists need to figure out the rate at which the population is multiplying. By comparing birth and death rates over a set period of time, ecologists can determine how much a population is increasing or decreasing on a per individual basis. Ecologists call this the **per capita rate of growth**. If they know the per capita rate of growth and they know how many individuals make up the population, it's relatively easy to estimate how the population's size might change over time. For example, during the 1990s, Missouri's river otter population had a per capita growth rate of about 1.28. This means that each spring, each otter contributed 1.28 offspring to the population. In 1993, there were about 2,500 otters making up Missouri's population. What would the population size be in 1994? A simple formula will help us get the answer:

population size in one year = current population size X per capita growth rate

An ecologist would use symbols to write the same equation:

$$N_{t+1} = N_t\lambda$$

N_{t+1} = Population size at one year in the future (t + 1 means "time plus one")
N_t = Population size right now
λ = Per capita growth rate

If we put numbers into the equation we get:

$$N_{t+1} = 2{,}500(1.28)$$
$$N_{t+1} = 3{,}200$$

If we wanted to estimate the population's size at three years in the future, we could perform this calculation three times. Or, we could use this equation, which does the same thing:

$$N_t = N_0\lambda^t$$

Here, N_t stands for population size at t years in the future. N_0 stand for the population size you start out with. So, if we wanted to figure out the size of Missouri's otter population at three years in the future, we would plug numbers into the equation like this:

$$N_3 = 2{,}500(1.28^3)$$
$$N_3 = 2{,}500(2.10)$$
$$N_3 = 5{,}250$$

This method of estimating a population's growth rate assumes that each member of the population has the same chance of giving birth or dying as any other member of the population. Of course, this isn't often the case. Usually birth and death rates vary with the ages of individuals in the population. When this is true, the per capita rate of growth must be calculated for each age class of the population. To do this, ecologists use a sort of spreadsheet called a **life table**. Life tables provide a more accurate estimate of how populations might change over time.

Predators, such as coyotes, are a limiting factor for prey populations. A shortage of prey, such as rabbits, acts as a limiting factor for predator populations.

Many factors limit how large a population can grow.

Over time, exponential growth can lead to staggering numbers. If Missouri's river otter population was allowed to grow unchecked, in just over a century there would be nearly 9 *quadrillion* otters—9,000,000,000,000,000—enough to completely cover the face of the earth!

Obviously, this could never happen. As the population grew, competition for food, water, space, den sites and other resources would become fierce. With each otter getting a smaller and smaller share of resources, eventually, some of the otters would die. Poor nutrition would lead to lower birth rates. Offspring would die of malnourishment. As the population became more crowded, it would become easier for diseases and parasites to spread from one otter to another. These factors that slow a population's growth or prevent it from existing in certain areas are called **limiting factors**.

Many things can act as limiting factors. Some limiting factors are abiotic. Sunlight, precipitation, the amount of nutrients in the soil or the amount of oxygen dissolved in water are limiting factors for many populations. Temperature also is an important abiotic limiting factor. Instead of a thick coat of fur, armadillos are covered in hard, bony plates. These plates protect them from predators, but the lack of fur makes armadillos prone to frostbite and freezing to death in cold weather. For armadillos, cold temperatures have kept their population from growing and expanding into northern Missouri.

Some limiting factors are biotic. We learned that trapping is an important limiting factor for Missouri's river otter population. For a population of smallmouth bass, otters—which prey upon bass—are a limiting factor. From these two examples, we might guess that predation—whether from humans or other organisms—is a major limiting factor for many populations. Sometimes competition with other organisms is a limiting factor. Bur oak seedlings compete with other trees for sunlight, water and nutrients. Songbirds may compete for nesting sites. The availability of food, a shortage of mates, an outbreak of disease, an infestation of parasites—all of these can be limiting factors.

Limiting factors slow population growth by affecting birth and death rates. When there are few limiting factors, births increase and deaths decrease. When there are many limiting factors, births decrease and deaths increase. In the case of river otters, trapping increased death rates, lowering the population's size. This led to fewer otters reproducing, so births also decreased. The opposite happened with fish populations. With fewer otters, fish deaths decreased and births increased. This caused fish populations to rebound.

Some limiting factors affect growth regardless of the population's density; other limiting factors affect growth in relation to the population's density.

A fish kill from a toxin is an example of a density-independent limiting factor.

Some limiting factors affect a population regardless of the population's density. Consider what an ice storm might do to an armadillo population, what a drought might do to a population of water-loving plants, or what a toxin spilled into a stream might do to a fish population. In each of these cases, the limiting factor causes the population to decrease regardless of how densely crowded the population is. Limiting factors that affect a population regardless of its density are called **density-independent factors**.

Other limiting factors affect a population in relation to the population's density. Consider the probability that a deadly disease could be transmitted from one member of a population to another. If members of the population are spaced far apart, the probability of transmission is low. However, if members of the population are spaced close together, the probability of transmission is higher. Limiting factors that affect a population in ways related to the population's density are called **density-dependent factors**.

To illustrate how density-dependent factors affect population growth, let's consider a coyote population and one of its limiting factors, the availability of rabbits to eat *(Figure 3.5)*. When the coyote population's density is low—about 0.2 coyotes for each square kilometer—each coyote gets a larger share of rabbits to eat. Because of this, survival rates are higher. Higher survival rates plus better nutrition leads to birth rates of 7-9 pups in each litter, and the coyote population grows. When the coyote population's density is higher—about 2 coyotes per square kilometer—the number of rabbits in the area is divided among more coyotes. This means that each coyote gets fewer rabbits to eat. If more coyotes compete for the same number of rabbits, it's likely that some of the coyotes will starve. With low survival and poor nutrition, birth rates decrease to about 4 pups in each litter. When this happens, the coyote population will stop growing, and perhaps even decrease in size. What we learn from this example is that density-dependent factors are important regulators of population size.

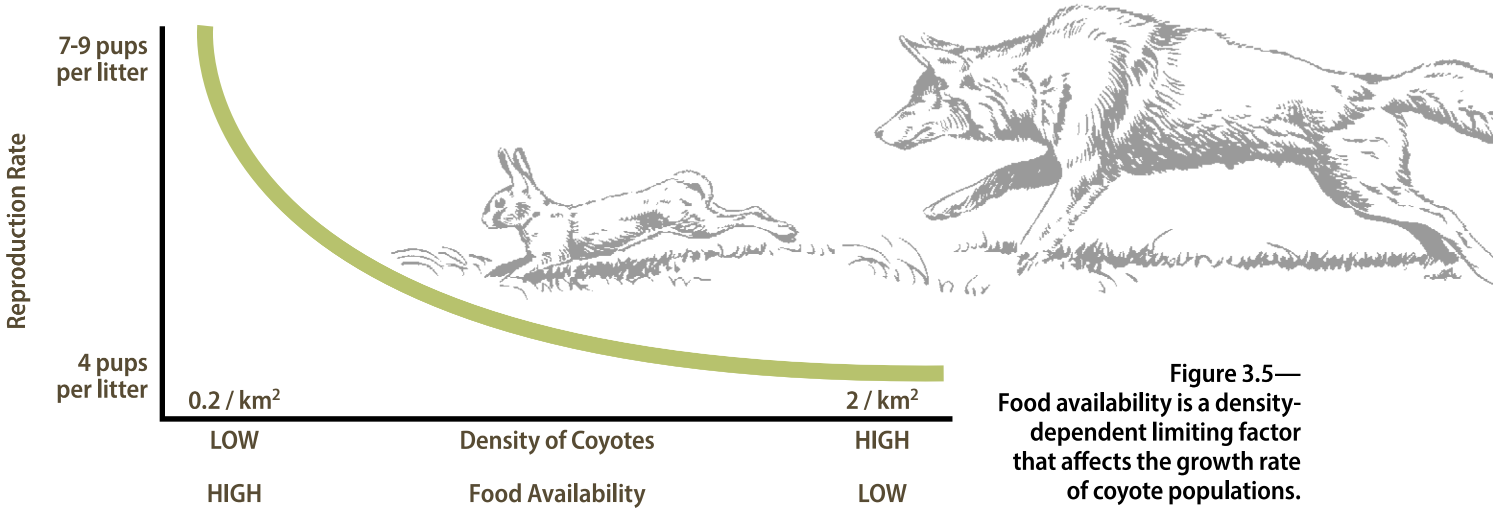


Figure 3.5—Food availability is a density-dependent limiting factor that affects the growth rate of coyote populations.

Births, Deaths and Hunting

Deer, turkeys, ducks and many other animal populations are hunted for food, clothing and sport. Rule makers consider social, economic and ecological factors when setting hunting seasons, bag limits and harvest methods for these populations. Wildlife biologists, using what they know about how populations grow and change, provide valuable scientific input to the rule makers.

Wildlife biologists often represent population change with a simple formula:

population change = (births + immigration) - (deaths + emigration)

According to this formula, if we have a population of 8.5 million mallards, and hunters kill 10,000 on the opening day of duck season, on the second day of hunting season there will be 10,000 fewer mallards. The formula works well in the short term. However, if we try to predict the mallard population a year into the future, the math gets a little fuzzy. This is because the four variables on the right side of the equation—births, deaths, immigration and emigration—are not independent, but affect each other. A decline of 10,000 ducks might lead to a drop in the population's size next fall, but it might also cause mallard numbers to increase. How can this be? The answer has something to do with **compensatory mortality**.

Consider a mallard population in which winter food is a limiting factor. With a large population, there isn't enough food to go around, and 10,000 ducks die each year of starvation. If hunters kill a percentage of the population, there is more food available to the surviving mallards, and fewer ducks starve. In this example, the number of mallards that die will be the same regardless of whether hunting or starvation is responsible. Thus, if hunters kill 6,000 ducks, 4,000 will die from starvation, and if hunters kill 8,000 ducks, 2,000 will die from starvation. This is called compensatory mortality because different causes of death balance out or *compensate* for each other. **Additive mortality** occurs when different causes of death add to each other. When additive mortality occurs, if hunters kill 5,000 ducks, it would add to the 10,000 that normally die of starvation. Thus, the population would decrease by 15,000 ducks.

Although there is considerable debate among biologists about whether hunting is additive or compensatory, for most species, hunting seems to be compensatory up to a point. Setting harvest limits below this point allows hunters to take a percentage of the population without causing long-term declines. However, if individuals are harvested beyond this point, hunting becomes additive, and the population does not rebound to its former size over the next breeding season. Without correction, additive mortality can cause the population to decline or even disappear—something wildlife managers strive to avoid.

For most species, including waterfowl, hunting seems to be compensatory up to a point.

Population growth slows as population size nears carrying capacity.

Because of limiting factors, populations do not grow exponentially for very long. As with the coyote population, competition for scarce resources lowers birth rates and increases death rates. This causes exponential growth to slow down and level off. If we plotted this leveling off on a graph, it would form an S-shaped growth curve like the one shown in Figure 3.6.

When a population's growth reaches the point where it levels off, we say the population has reached its carrying capacity. **Carrying capacity** is the number of individuals a given area can support at a given time. Ecologists often use K to represent carrying capacity. Resource managers use the concept of carrying capacity to estimate how much habitat must be conserved to maintain healthy populations of plants, animals and other organisms.

After an initial burst of population growth, the size of most populations hovers around carrying capacity. At carrying capacity, the number of offspring born equals the number of individuals that die. When a population's size grows larger than carrying capacity, there aren't enough resources to go around. There are more deaths in the population than births, and this brings the population size back toward carrying capacity. When a population's size is less than carrying capacity, there are more than enough resources to go around. There tend to be more births than deaths, and this also brings the population size closer to carrying capacity.

Carrying capacity isn't a fixed amount, though. Resources can become more abundant or scarce, and limiting factors can increase or decrease over time. If you planted a larger garden, you would increase the resources—food and space—available to a population of insect pests living there. Because of this, the carrying capacity for your garden would increase, and there would be more insects. Although Missouri's otter population is close to carrying capacity right now, if more wetland habitat was created or if the Conservation Department closed the trapping season, we would expect the state's carrying capacity for otters to increase.

Sometimes, populations reach sizes humans can't tolerate before they reach carrying capacity. River otters in Ozark streams, Canada geese on a golf course, white-tailed deer in a city, weeds in a soybean field, *Streptococcal* bacteria (which cause strep throat) in a biology classroom—these are all populations we try to keep below carrying capacity. Your vegetable garden could probably support a much larger population of insect pests than you will tolerate. To keep pest populations low, you might release lady beetles to eat the pests, spray soap to make the vegetables inedible to insects or use pesticides. When populations begin to grow higher than humans can tolerate, resource managers use similar methods to bring the populations back under control. There are many ways to do this. For example, resource managers can open hunting or fishing seasons and set harvest limits to keep game populations healthy and at levels that reduce conflicts with the human population. Managers also can keep populations low by managing habitat. When Canada goose populations get too big in a park or on a golf course, managers can let shoreline vegetation grow tall to make the habitat less appealing to geese. ▲

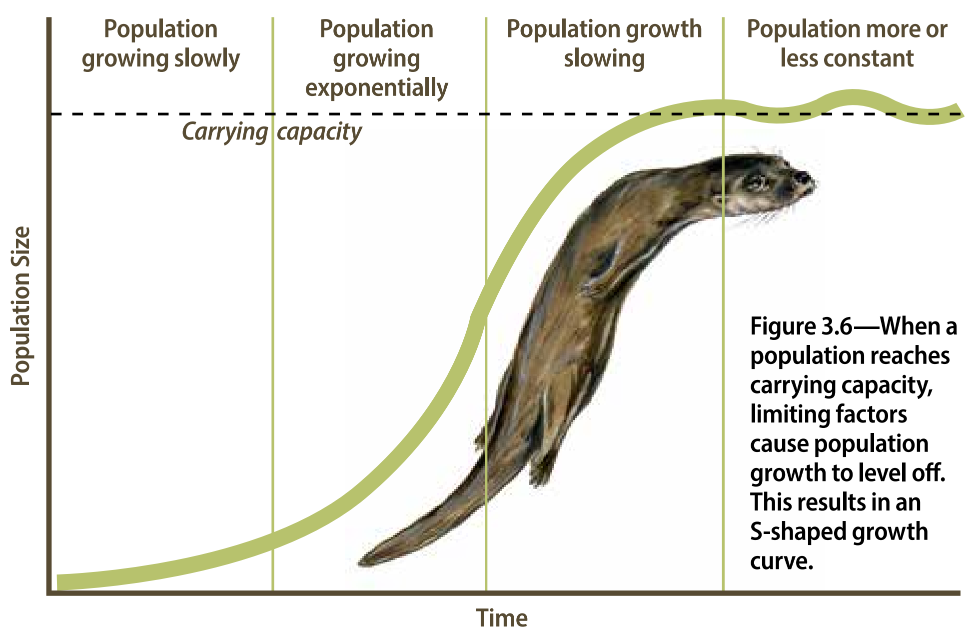


Figure 3.6—When a population reaches carrying capacity, limiting factors cause population growth to level off. This results in an S-shaped growth curve.

Keeping Missouri's Deer Under Cultural Carrying Capacity

Every day, Conservation Department managers are asked: "Why don't you do something about the deer herd?"

Some people ask this question believing there aren't enough deer. They want to know what's being done to increase deer numbers. Others believe there are too many deer and want to know what's being done to reduce deer numbers. Resource managers are constantly trying to find a balance between one person's "too many" and the next person's "not enough."

Missouri's white-tailed deer population illustrates the difference between biological carrying capacity and **cultural carrying capacity**. Although Missouri is currently home to over a million deer, the biological carrying capacity—the number of deer that the habitat can support—has not yet been reached. However, the cultural carrying capacity—the number of deer that people will tolerate—has generally been reached, and in some areas, exceeded.

What are the consequences of high deer numbers? Although rare in Missouri, deer can overbrowse forests which eliminates understory plants and creates long-term changes in forest communities. Damage to agricultural crops, fruit orchards, commercial nurseries and Christmas tree farms can inflict significant financial losses on farmers and nursery owners. Residents in urban and suburban areas can experience damage to vegetable and flower gardens. And, anyone who drives seems concerned about deer-caused vehicle accidents.

Whether a deer population increases, decreases or remains stable depends upon the balance between births and deaths. Birth rates for Missouri deer are high, with most 2-year-old does producing twin fawns and 10 to 15 percent producing triplets. In northern Missouri, where birth rates are highest, about 35 percent of 1-year-old does produce a fawn.

Studies show that death rates for fawns during their first 6 months of life may exceed 40 percent. Without hunting, though, death rates for older deer are less than 5 percent. With few natural predators remaining, hunting has become the leading cause of deer deaths in most of Missouri. Each year hunters take 40 to 70 percent of the antlered bucks and up to 25 percent of the does. This indicates that hunting is an important tool that resource managers can use to control deer numbers.

Not all hunters affect deer populations the same, however. Hunters who shoot only bucks have less of an impact on deer populations than hunters who shoot only does. Since one buck can mate with many does, males can remain at much lower numbers than does without affecting the population's overall birth rate. Indeed, population models show that harvests of up to 80 percent of the bucks from a herd have little effect on the overall population growth. Similar harvest of does, however, has a substantial effect on slowing population growth.

It makes sense, then, that to maintain deer numbers at cultural carrying capacity or lower deer numbers in areas where cultural carrying capacity is exceeded, the Conservation Department has regulations to encourage the harvest of does. During the November portion of the firearms deer season, hunters can harvest only one antlered deer. However, in the northern half of the state, where deer densities are highest, hunters—with the right permits—also can harvest an unlimited number of does. In addition, in the northern two-thirds of the state any antlered deer a hunter harvests must have at least four antler points on one side of its rack. The objective here is to restrict the number of bucks that can be taken, thereby increasing the likelihood hunters will harvest does. A benefit of this regulation is that it allows more bucks to attain older age and larger antlers—something many hunters would like to see.

Hunting is an important tool that resource managers use to control deer numbers.

A shorebird probes its bill in the muck of a mudflat to find aquatic invertebrates to eat. This connection—between a predator and its prey—is just one of countless interactions that occur in nature.

BIG IDEAS:

- Organisms compete for limited resources.
- Competition affects the growth, survival and reproduction of the organisms involved.
- A species' niche describes its way of life and role in an ecosystem.
- Two species cannot have the same niche in an ecosystem.
- Exploitation benefits one organism but harms another.
- Adaptations help organisms exploit other organisms or avoid being exploited.
- Commensalism benefits one organism but does not affect another.
- Mutualism benefits each organism that participates in the interaction.
- Interactions maintain balance within ecosystems.

Interactions AMONG ORGANISMS

On a mudflat, little birds with long legs skitter along the water's edge. The oozy mud and mucky water are a virtual insect soup, and the birds—famished from a long migration—eat quickly and greedily. Although the scene looks peaceful, there is an intense competition raging with shorebird pitted against shorebird, each trying to gather enough to eat before the supply of insects runs out.

At the edge of a marsh, a mink and a muskrat are locked together in mortal combat. The mink, trying to find a killing hold, bites the muskrat's neck. The muskrat shakes off the mink. Fur flies. The mink springs back at the muskrat, and the two tumble, snarling and squealing, through the vegetation. For the mink, victory means a full belly; for the muskrat, victory means survival.

Along a weedy fencerow, a bumblebee touches down on the lavender blossom of a milkweed plant. For the plant, the bumblebee is a delivery driver, transferring pollen from one flower to another, thereby ensuring a future crop of milkweed. For the bee, the flower is a grocer, providing nectar to make honey, thereby ensuring food for the next generation of bumblebees.

These are just a few of the countless interactions that occur among organisms in nature. Ecologists define an **interaction** as a relationship between two or more organisms that affects the growth, survival or reproduction of the participants. Ecologists categorize interactions as competition, exploitation or mutualism based on the costs and benefits resulting from the relationship. **Competition**—perhaps the most common interaction in nature—occurs when neither organism benefits from the interaction. **Exploitation** occurs when one organism benefits, while another organism is harmed from the interaction. **Mutualism** occurs when both organisms benefit from the interaction. In this chapter, we will explore competition, exploitation and mutualism and examine how these interactions affect the participants involved.

Organisms compete for limited resources.

American golden-plovers migrate long distances between nesting and wintering grounds.

Shorebirds are the marathoners of the bird world. Although many birds migrate, shorebirds fly extreme distances between their nesting and wintering grounds. Take, for instance, the American golden-plover, which nests in the Arctic tundra, yet winters in Argentina. The roundtrip flight between these two locations averages 25,000 kilometers—not bad for a bird the size of a robin. During migration, plovers often zip through the air at altitudes of 6,000 meters and speeds faster than you can legally drive on the interstate. When crossing oceans, they have been known to fly nonstop for two days! You couldn't pump enough fuel into a jumbo jet to accomplish the same feat.

To fuel their epic migrations, golden-plovers and other shorebirds need to eat—a lot. And, nothing satisfies the appetite of a hungry shorebird more than a slew of squirming mosquito larvae, leeches or other aquatic invertebrates. The best places to find such fare are the mudflats and shallow pools that dot the Midwestern landscape. Mudflats, however, are hard to find. Sometimes they are covered by floods; other times they are baked dry by drought. Most are small and spaced far apart. Because of this, shorebirds often concentrate in whichever tiny mudflat they can find. And, as you might expect, competition for food in these muddy pools is intense.

Mudflats in the Midwest are small and far apart. Consequently, competition for food among shorebirds is intense.

Ecologists define **competition** as a struggle among organisms to use or consume a limited resource. Because every organism needs certain resources to grow, survive and reproduce, competition is common in nature. Sometimes competition involves organisms trying to gather as much as they can of a shared resource before it runs out. Shorebirds foraging in a mudflat, fish slurping up a hatch of mayflies, squirrels gathering acorns in a park—all are examples of what ecologists call **indirect competition**. At other times, organisms actively take or defend a resource from other organisms. In the fall, blue jays often harass squirrels—sometimes by pecking the squirrel on the head—to steal acorns. Competition isn't limited to just animals, either. Trees in a forest compete for sunlight. Fungi on a rotting log compete for space. The bacteria living in your gut compete for nutrients. In nature, whenever and wherever resources are limited, competition will occur.

Often, members of the same species compete with each other for limited resources. At a mudflat, each American avocet competes with other avocets for aquatic insects to eat. On the nesting grounds, avocets compete with each other for mates and nesting sites. This kind of competition among members of the same species is called **intraspecific competition**. When competition involves different species—such as when avocets compete with sandpipers, yellowlegs and stilts for food—ecologists call it **interspecific competition**.

American avocet

Pectoral sandpiper

Greater yellowlegs

Black-necked stilt

Gathering resources exposes organisms to predators.

Competition affects the growth, survival and reproduction of the organisms involved.

Imagine being adrift in a life raft with 10 other people. You have enough food to last for a few days, but each time someone eats, there is less food left for everyone else. The same thing happens in nature. When a resource is limited, each time an organism consumes part of the resource, a smaller amount is left for others to use. As organisms continue consuming the resource, over time it becomes scarce. When resources become scarce, competition becomes fierce. And, when competition is fierce, life gets tough for the organisms involved.

When resources are scarce, competition can affect the growth of organisms. Imagine you're planting flowers in two equally sized pots. As an experiment, you plant five flowers in one pot, and 10 flowers in the other pot *(Figure 4.1)*. Both pots contain the same kind and amount of soil, both are placed so that the plants receive the same amount of sunlight, and you give each pot the same amount of fertilizer and water. Which pot's flowers do you think will grow better? If you said the pot with five flowers in it, you'd be right. Ecologists have done many versions of this experiment, and the results are always the same: When a greater number of organisms compete for the same amount of resources, the growth of each organism is diminished.

Competition for scarce resources can affect the survival of some organisms. If organisms don't get enough to eat or drink, they will eventually die. Competition for food can cause organisms to spend more time foraging. This is risky because it exposes organisms to predators more than if they were hiding or sleeping. Competition for space can affect survival by causing some organisms to use marginal habitats where they might be more exposed to weather and predators.

When resources are scarce, competition can affect the reproduction of some organisms. To reproduce, female shorebirds must consume enough food during their northward migration to survive, power their flight to the nesting grounds, and produce eggs. When competition forces a female shorebird to go hungry, her odds of survival and ability to reproduce are diminished.

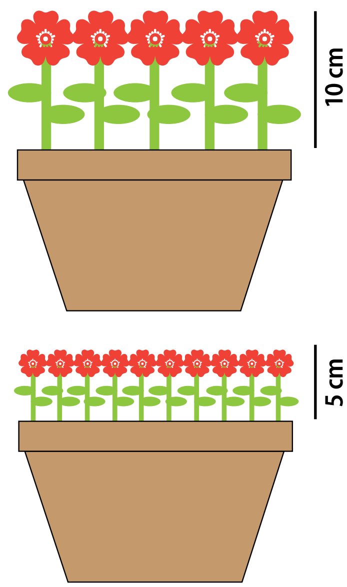


Figure 4.1—When fewer organisms compete for resources, their growth increases. When more organisms compete for the same amount of resources, their growth is diminished.

Timber Stand Improvement

Take a moment to consider the products you've used today, and it's likely more than half of them came from trees. Some are obvious. The pages in this book, the lumber framing your school, the tissue you blew your nose in—all come from trees. Some of them aren't so obvious. Clothing fabrics, carpeting, cosmetics, even the circuit boards in your laptop—these, too, come from trees. In total, about 5,000 products—from charcoal to chewing gum—come from trees.

Fruits, nuts and other products can be obtained from living trees. To get most products, however, trees must be cut down. Harvesting trees in Missouri, when done in a responsible manner, can provide wildlife habitat and forest products for generation after generation. Missouri's trees are a renewable resource but, like other crops, must be managed properly to produce a high-quality product in a reasonable amount of time. Foresters use what they know about competition and how it affects different tree species to make wise management decisions.

After harvest, new trees quickly recolonize the openings created in the forest. In these areas, 10,000 to 12,000 seedlings may grow on a single hectare. Competition for sunlight and moisture is fierce. Unless some of the seedlings are thinned out, all the seedlings grow slowly and poorly. Over time, a few of the strongest seedlings may outcompete their rivals, sending branches higher to gather sunlight or roots deeper to collect water. Without enough sunlight or water, weaker trees eventually die. In addition, herbivores, pests and disease thin out a proportion of the seedlings. When the trees are large enough to harvest again, the forest will have fewer than 250 trees per hectare. This natural thinning usually takes 150 to 250 years depending on the type of trees.


Foresters cut down unwanted trees to reduce competition and improve a stand of timber.

Using special management techniques, foresters can reduce this time span to less than 100 years and improve the health and quality of the surviving trees. One of the techniques foresters use is called **timber stand improvement**. To improve a stand, or segment of the forest, foresters remove unwanted or low-value trees and those with crooked or damaged trunks. They leave desirable trees that have tall, straight trunks free from insect, disease and fire damage. By reducing competition for sunlight and water, this technique allows the desirable trees to grow faster and produce higher-quality wood. With less energy needed for competition, trees that remain can devote more energy to surviving diseases and fighting off pests. They also have more energy for reproduction, so nut and seed production typically increases. This provides extra food for wildlife and a seed source for the next generation of trees.

A species' niche describes its way of life and role in an ecosystem.

Imagine you are a world-renowned expert on the greater yellowlegs, a species of shorebird that migrates through Missouri in the spring and fall. If I asked you to tell me everything you know about yellowlegs, our conversation might stretch on for days. We might begin by talking about the range of environmental conditions that yellowlegs can tolerate—what temperature extremes they can survive, how much humidity they can handle, at what altitude they can nest and fly. Then you might continue with what yellowlegs need to grow, survive and reproduce. What foods yellowlegs eat might take several hours to describe, as would their nesting requirements—what habitats they use, where they place their nest, how they hide the nest, what materials they use to build the nest, blah, blah, blah. We might wrap up by talking about how yellowlegs interact with their environment and other species in it. You'd tell me which species yellowlegs compete with for food and nesting sites, which species are predators of yellowlegs, and what role yellowlegs play in the ecosystems they inhabit.

Everything you've described about greater yellowlegs is a part of its **niche**. To an ecologist, a niche describes everything affecting a particular species' existence, including the range of environmental conditions the species can tolerate, what the species needs to grow, survive and reproduce, and how the species interacts with its biotic and abiotic environment. In other words, the niche describes a species' way of life and its role in an ecosystem.

A species' **fundamental niche** includes the environmental conditions the species can tolerate and the resources it is capable of using under ideal conditions. In nature, however, conditions are rarely ideal. Other species may compete for the same resources or be predators. Competition and predation may cause a species to use only part of the resources that make up its fundamental niche. This more restricted range of resource use is known as the species' **realized niche**—the portion of the fundamental niche a species uses in the presence of other species. For example, greater yellowlegs are capable of gathering food anywhere on a mudflat from the shoreline to water 4 inches deep. When different species of shorebirds use a mudflat, though, yellowlegs typically forage in water 3 or 4 inches deep, leaving shallower or deeper areas to other species that are more efficient at gathering food there *(Figure 4.2)*.

Understanding niches helps us understand how species interact with each other. Species with similar niches are more likely to compete for resources, while species with dissimilar niches are less likely to compete for resources.

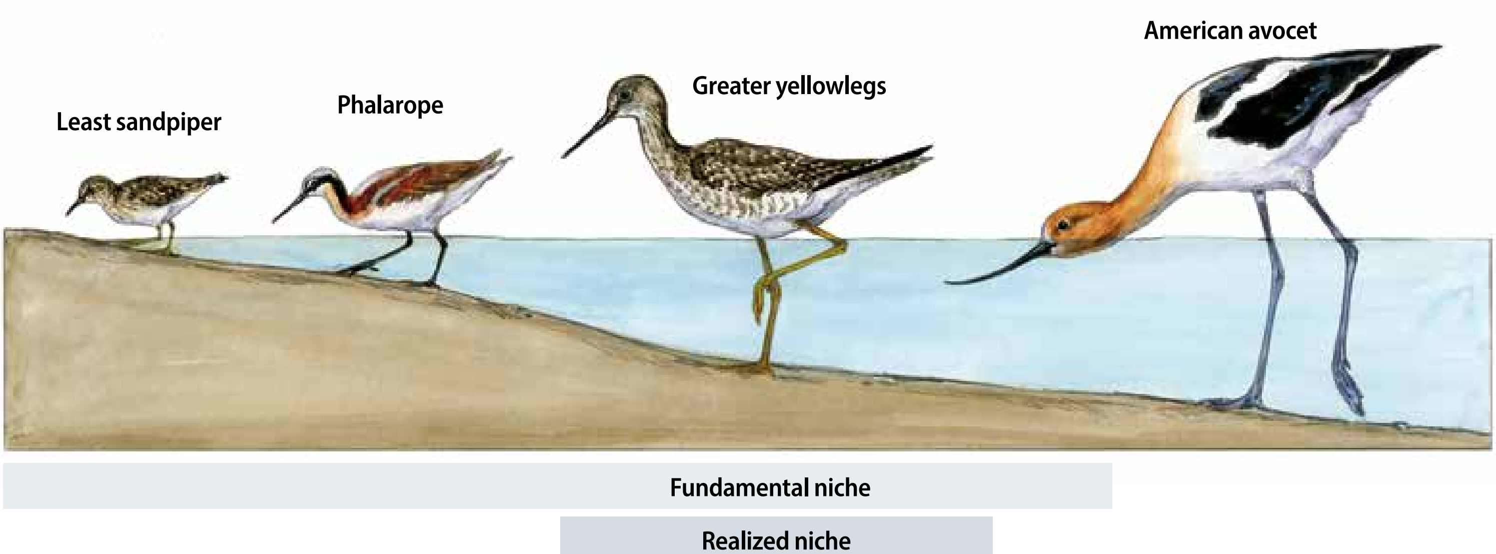


Figure 4.2—A species' fundamental niche is always broader than its realized niche. Under ideal conditions, greater yellowlegs can forage from the shoreline to water 4 inches deep. However, competition with other shorebirds often causes yellowlegs to gather food in water 3 or 4 inches deep.

Managing Wetlands

Ask a resource manager about wetlands, and the word "dynamic" is bound to come up. By this, the manager means wetlands change a lot. Wetlands are wet—most of the time. Sometimes, however, they dry out. Other times, they flood. A wetland after a spring deluge looks quite different than the parched mud hole of a mid-summer drought.

The land in a wetland seems flat, but isn't. Within wetland pools, mounds of high ground border shallow sloughs, adding additional variety to the landscape. These small differences in elevation, combined with the ebb and flow of water, create an ever-changing patchwork of habitats that fulfill the niche requirements of a variety of organisms, from mallards to muskrats.

More than 85 percent of Missouri's historic wetlands are gone. Many were drained. Others dried up when rivers were channelized and flood-control levees were built. During the last 50 years, many government agencies, nonprofit groups and private landowners have worked hard to restore wetland habitats. Today, the Conservation Department manages more than 45,000 hectares of wetlands throughout the state. Many of these wetlands require intense management to mimic the natural ebb and flow of water that occurs in unaltered wetlands. Managers use a system of pumps, canals and water-control structures to do this.


Wetland managers use water-control structures to mimic the ebb and flow of water that occurs on a natural wetland.

Often, managers begin flooding wetland pools in late summer. As the water slowly creeps across the pool, it creates mudflats for migrating shorebirds and shallowly flooded vegetation, which attracts blue-winged teal. By October, the water is a little deeper and covers more of the pool, providing resting and feeding areas for large flocks of dabbling ducks, such as mallards, that dip their heads underwater to strain seeds, vegetation and aquatic insects through their bills. The deeper water also affords turtles and frogs a place to hibernate through the winter. By mid-winter, if it's not frozen over, the water is at its deepest and provides areas for diving ducks, such as scaup, redheads and canvasbacks, that swim underwater to catch food.

In early spring, flooded vegetation begins to decompose, providing homes and food for a flush of aquatic insects. Waterfowl come back through Missouri around March and feast on the insects. After ducks and geese depart in late spring, managers begin slowly drawing water off wetland pools. As the water recedes, it exposes mudflats for shorebirds, provides breeding pools for frogs and salamanders and disperses the seeds of wetland plants. The various water depths and exposed areas provide niches for different plants to germinate and grow. Ground exposed in early May might foster smartweeds, while ground exposed in mid-May might give rise to wild millet. To meet the niche requirements of the greatest number of plants, wetland managers try to take water off a pool slowly.

Sometimes managers leave pools flooded throughout the summer. This provides spawning grounds and aquatic nurseries for fish. When the wetlands dry up later in the summer, the fish become concentrated into ever-shrinking pools. This provides easy pickings for young herons and other wading birds newly abandoned by their parents and just learning to hunt for themselves.

Resource managers will never be able to improve upon nature. However, by manipulating how deep, how long and when wetland pools are flooded, managers can meet the niche requirements for a vast array of species. Pretty dynamic, wouldn't you say?

Two species cannot have the same niche in an ecosystem.

In 1932, a 22-year-old Russian student named Georgyi F. Gause performed a series of brilliant experiments that turned the field of ecology on its head. Gause wondered what would happen when species with similar niches competed for the same resource. To find out, he carefully measured the population growth of two different *Paramecium* species. He started by growing the two species in separate beakers of water, and both populations thrived. When he grew both *Paramecium* species in the same beaker, however, one population always survived, while the other always died. Gause concluded that one species was better at competing for food, which caused the other species to eventually die. These results led Gause to form the **competitive exclusion principle**, which states that two species with identical niches cannot coexist over time. This theory—also called Gause's Law—is a key idea of ecology.

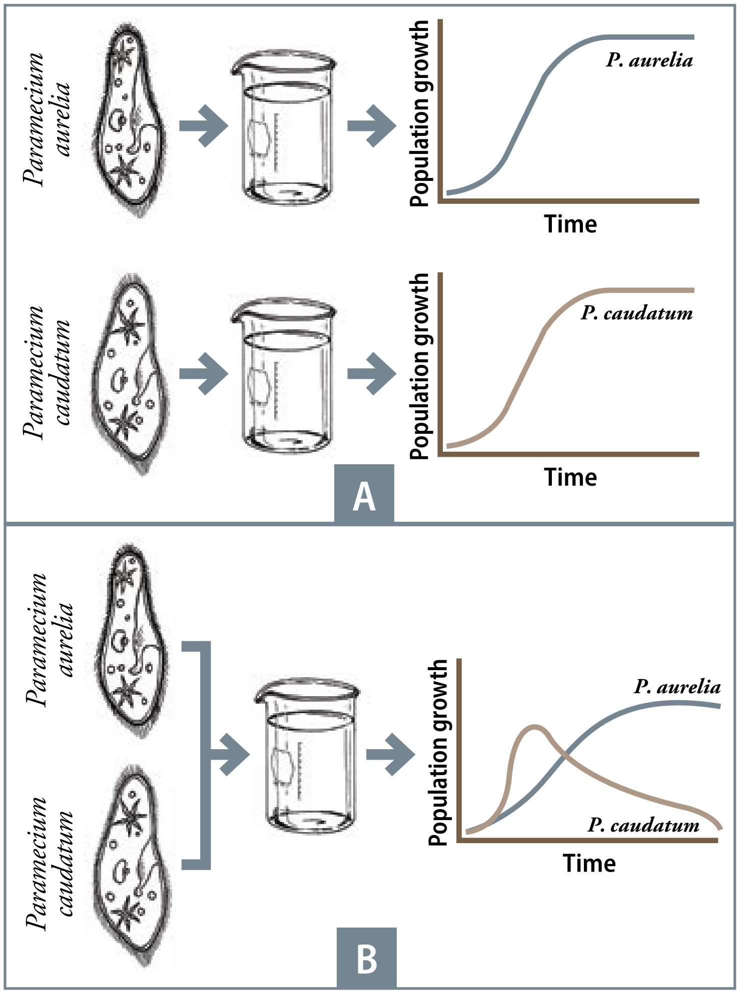


Figure 4.3—When Gause grew two *Paramecium* species in separate containers, both thrived (A). When he grew both species in the same container, one survived and the other died (B).

Competitive exclusion predicts that when two species compete for exactly the same resources, one will be more efficient than the other at gathering those resources. This will cause the more efficient species to fill the niche with more of its offspring, eventually leaving no resources for the less efficient species. With no resources to use for growth, survival and reproduction, the less efficient species eventually dies off. This explains why two species cannot have the exact same niche in an ecosystem.

Species can have *similar* niches and coexist, but not *identical* niches. Close observation of two similar species usually reveals subtle differences in what each eats, how each gathers food, where each nests, or some other aspect of each species' lifestyle. These subtle differences are often enough to allow two similar species to coexist in the same ecosystem. For instance, different species of shorebirds can often be found foraging on the same mudflat. Since each shorebird desperately needs to refuel, and since each seems to be going after the same kinds of food, you might think competitive exclusion would come into play. If you were to carefully observe the shorebirds, though, you would notice several differences in where each species forages and how each captures food. Long-legged avocets forage in water 6 inches deep, swinging upturned bills side to side to snag minnows and swimming invertebrates. Water 4 inches deep might attract greater yellowlegs, while phalaropes can be found foraging in water 2 inches deep. Least sandpipers might be found running along the water's edge, probing in mud with their bills for snails, worms and insect larvae *(Figure 4.2)*. By foraging in different places and catching prey in different ways, shorebirds lessen competition and avoid competitive exclusion. When species with similar niches use a resource in slightly different ways, ecologists call it **resource partitioning**.

American avocets forage in water too deep for most shorebirds to use.


Predators, like this bobcat, get energy by eating other animals.


Herbivores, like rabbits, get energy by eating plants.


Parasites, like ticks, get energy by feeding on their hosts.

Exploitation benefits one organism but harms another.

In nature, every organism needs energy, and nearly all organisms risk becoming energy for something else. **Predators** get energy by catching, killing and eating prey. A bobcat eating a rabbit and a bat eating a moth are both examples of predation. **Herbivores** get energy by eating plant parts. A rabbit clipping clover is an example of herbivory. **Parasites** get energy by feeding on the blood, intestinal fluids or tissues of another organism, called the **host**, usually without killing it. Some parasites, such as ticks and leeches, live on the outside of their hosts. Other parasites, such as tapeworms, live inside their hosts. While each of these interactions—between predator and prey, herbivore and plant, and parasite and host—is slightly different, they all have one thing in common: One organism benefits from the relationship, while the other organism is harmed. Ecologists often group these kinds of interactions together and call it exploitation. Whenever one organism makes its living at the expense of another, exploitation occurs.

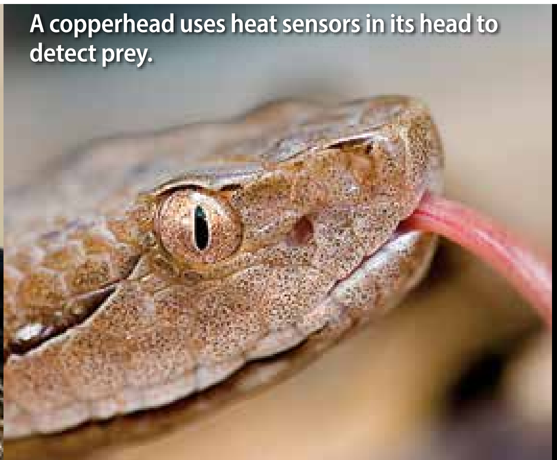
Predators, herbivores and parasites can be limiting factors on other populations. By killing or weakening the organisms they exploit, predators, herbivores and parasites increase deaths and decrease births in prey, plant and host populations. Likewise, shortages of prey, plants and hosts can lead to starvation or malnourishment in predator, herbivore and parasite populations.

Adaptations help organisms exploit other organisms or avoid being exploited.

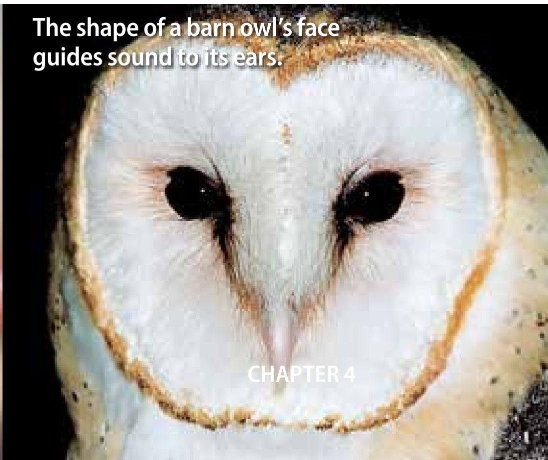
Predators have a stunning arsenal of senses to help them find prey. Some predators, particularly birds of prey, have keen eyesight that helps them detect animals to eat. A red-tailed hawk can spot a rabbit scratching its ears 2 kilometers away. Many predators, from coyotes to catfish to copperheads, use smell and taste to locate prey. Catfish are known as swimming tongues because nearly every part of their bodies—from their cat-like barbels to the tips of their tails—is covered with taste buds. (If you were a catfish, you could taste a cookie just by touching it.) This, coupled with a highly developed sense of smell, helps catfish find food in dark, muddy water. Many nocturnal predators find prey using only their hearing. The flat, concave shape of a barn owl's face acts like a radar dish to help guide the quietest of sounds to its ears. By judging the time difference between when the sound is heard in its left and right ear, barn owls can determine the exact location of a squeaking mouse in complete darkness.

Red-tailed hawks use keen eyesight to spot prey.

A copperhead uses heat sensors in its head to detect prey.



The shape of a barn owl's face guides sound to its ears.



Thwarting a Different Kind of Parasite

Not all parasites make their living by feasting on other organisms. Ecologists have a much broader definition for parasite. It includes organisms that take advantage of their hosts in other ways. For instance, brown-headed cowbirds are notorious **brood parasites**. Instead of building their own nests and raising their own chicks, cowbirds lay their eggs in the nests of other birds. The other birds raise the cowbird chicks, which hatch earlier and grow faster than the parents' own young. Because cowbird chicks are bigger, they can reach higher to snatch food from the parent before other chicks can get it. Sometimes, this causes the smaller chicks to starve. Other times, cowbird chicks physically force smaller chicks out of the nest.

Cowbirds parasitize more than 220 different bird species, ranging from tiny chickadees to large ducks. Not all birds make good foster parents. If a yellow warbler finds a cowbird egg, it either abandons its nest or builds another nest on top of the first one. This kills the cowbird egg. Yellow warblers may stack several nests on top of each other, each one containing a cowbird egg. Prairie birds, which have adapted to cowbird parasitism over time, are more likely to kick cowbird eggs out of their nests. Forest-dwelling birds, which were not historically exposed to cowbirds, suffer the most. When their nests are parasitized, most parent birds wind up loosing their own young and raising only cowbird chicks.


Brown-headed cowbirds are nest parasites, laying their eggs in the nests of other birds.

Because cowbirds quit laying eggs in mid-July, some birds are able to re-nest later in the summer and raise their broods free from cowbirds. Many species, however, migrate long distances and only have time to pull off one nest. If their first clutch is lost to cowbird parasitism, no young will be produced until next year's breeding season. As most birds live only a few years, this can lead to long-term population declines.

Prior to European settlement, cowbirds were nomadic, following immense herds of bison to feed on the insects the bison stirred up. When bison were wiped out and replaced by domestic livestock, cowbirds adapted to a more sedentary lifestyle. They now frequent woodland edges near pastures and crop fields. The clearing of forests has provided additional habitat for cowbirds and allowed them to expand into areas where they previously were absent. In large tracts of forest, however, cowbirds are rare because of the lack of open areas to forage in. As such, cowbird parasitism seems to depend on the landscape in which the host's nest is located. Nests in extensive forest or prairie landscapes sustain less parasitism, while those in fragmented forests interspersed with pastures and croplands are heavily parasitized.

This is important information for resource managers. In some parts of the country, managers trap and kill adult cowbirds and spend considerable time removing cowbird eggs from host nests. Scientists, however, believe these efforts have limited success. Although they might be effective on a local scale for helping rare and endangered species, killing, trapping and egg removal are not cost effective or successful on a large scale. Instead, most managers believe that the key to keeping cowbirds at bay has to do with habitat. Keeping large forests, like those in the Ozarks, from being divided into smaller tracts is the best way to reduce cowbird parasitism and increase the reproductive success of forest-dwelling birds.

Some predators have senses that humans don't. Most fish have a lateral line that runs down each side of their body from head to tail. This line of sensory cells can feel vibrations in the water, helping a fish find floundering prey. Bats use a kind of natural radar called echolocation to hunt and navigate in the dark. They emit high-frequency sounds that bounce off objects in the distance. By interpreting the echoes, bats can locate insects to eat and find their way through pitch-black caves. Pit vipers, such as copperheads and rattlesnakes, have heat sensors in their heads that detect the presence of warm-blooded birds and mammals on a dark night.

Predators lead a tough life, and finding prey is only half the task. Once prey is found, it must be captured and killed, and all predators are armed with adaptations to do this. Bobcats have hook-like claws that help them latch on to prey and long canine teeth to puncture the throat or spinal cord of animals, such as rabbits. Scorpions, venomous snakes and a tiny, mouselike mammal called the short-tailed shrew all use venom to subdue prey. Some animals—called ambush predators—hold very still, waiting for prey to come close enough so they can quickly strike. Great blue herons use this strategy, shading shallow water with their wings. When an unlucky fish swims by, the heron plunges its dagger-like bill into the water to snatch it up. Some predators work together to capture prey. White pelicans swim together to herd fish into shallow water, and coyote families hunt together to bring down large prey.

Prey organisms have adaptations that help them avoid detection or evade capture by predators. Many prey animals, such as walking sticks, rough green snakes and deer fawns, have shapes, colors and patterns that help them to blend in with their surroundings. Other species use noxious chemicals to keep predators from eating them. These species, such as monarch butterflies, striped skunks, and bumblebees, typically advertise their poor taste, foul smell or poisonous flesh with **warning coloration**. Bold patterns and bright colors are nature's way of saying, "I'm not good to eat."

Some harmless animals masquerade as distasteful or dangerous animals. Several species of clear-winged moths don't have stingers, but look and act just like wasps that do. When a harmless organism (called a

***Clockwise from above*—A striped skunk's bold black and white fur is an example of warning coloration. Although harmless, the hummingbird moth's black and yellow colors mimic the appearance of a bee or wasp. This is an example of Batesian mimicry. An example of Mullerian mimicry, a viceroy butterfly looks nearly identical to a monarch butterfly. Both taste bad, and predators that eat one likely will not try to eat the other.**

mimic) resembles a dangerous organism (called a **model**), ecologists call the relationship **Batesian mimicry**. Batesian mimicry only works when the harmful species outnumbers the harmless copycats. If too many copycats are around, predators quickly learn that the warning coloration is a trick, and begin eating both mimics and models.

Another type of mimicry, called **Müllerian mimicry**, occurs when dangerous or distasteful species resemble each other. Many species of bees and wasps employ the same pattern of yellow and black stripes to let predators know that they can sting. Monarch and viceroy butterflies look nearly identical and taste equally bad. By exhibiting the same orange and black color patterns, predators that try to eat a monarch usually don't repeat the experience with viceroys or other monarchs.

Many prey animals, such as rabbits and deer, are exceptionally fast and use their speed to avoid capture. Slower animals, such as turtles and armadillos, have shells or bony plates that help protect them from attack. Some prey species seek safety in numbers by gathering in herds, flocks or schools. This way, they have more eyes to watch for predators, and only individuals at the edge of the group are likely to be captured. Other prey species try to confuse or scare away predators. When a predator approaches an eastern hog-nosed snake, the snake puffs out its head like a cobra, hisses loudly and strikes. If this doesn't work, the hog-nosed snake rolls over on its back, writhes about, and plays dead. This acting job usually helps the snake avoid becoming a meal.

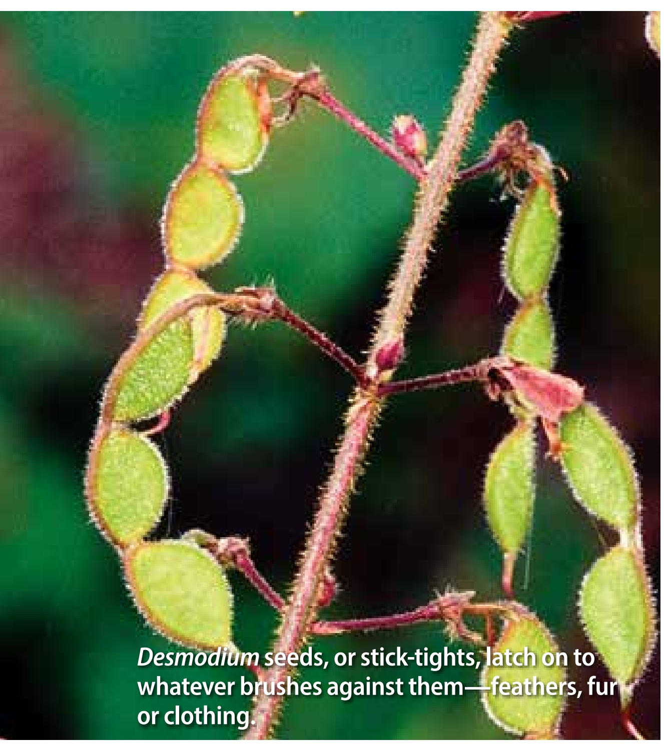
Plants employ structures or chemicals to defend against herbivores. Many plants, such as honey locusts, prickly pears and blackberries, have thorns or spines that make a herbivore think twice before taking a bite. Prairie grasses contain silica in their leaves and stems. This mineral—the same one found in sand and glass—makes the grasses hard to digest and wears down the teeth of herbivores. Many plants produce bitter or poisonous chemicals to keep herbivores at bay. Oak trees produce tannins that make their bark and foliage taste bitter. Milkweed—a common roadside wildflower—not only tastes bad, it also produces cardiac glycosides, a group of chemicals that alter heart rhythms. If enough milkweed is ingested, it can kill birds and mammals—even those as large as deer.

***Clockwise from left*—Little bluestem contains silica, a mineral that wears down the teeth of herbivores and is hard to digest. White-tailed deer counter this defense with teeth that have large surfaces to grind and pulverize tough plant tissues. A harmless hog-nosed snake tries to confuse a predator by flattening its head like a cobra's, hissing loudly and striking.**

Herbivores use a number of adaptations to counter a plant's defenses. White-tailed deer, like many herbivores, have teeth with large surfaces to grind and pulverize tough plant tissues. Animals, however, can't digest cellulose, a major component of plant tissue. To get around this biological snag, herbivores maintain colonies of bacteria, protozoans and yeasts in their digestive tracts. These microorganisms use special enzymes to break down cellulose, providing an energy-rich meal for themselves and the herbivores they live inside. Some herbivores, like cottontail rabbits, take digestion one step further—they eat their own droppings. By allowing plant materials to pass through their digestive tracts twice, rabbits can more thoroughly absorb all the nutrients found in the plants they eat. Eating droppings has another advantage: young rabbits acquire the microorganisms needed to break down cellulose from eating their mother's pellets.

Some herbivores use plant poisons for their own benefit. Monarch butterflies lay their eggs only on milkweed. Caterpillars eat the milkweed leaves and store the milkweed's cardiac glycosides in their body tissues. When the caterpillars turn into butterflies, they retain the milkweed's poisons, causing adult monarchs to have a terrible, bitter taste. This keeps predators from eating monarchs. Birds that swallow a monarch usually vomit it back up within a few seconds and rarely make the mistake of eating a monarch again.

Parasites have adaptations that help them find, feed on and disperse from their hosts. From 100 meters away, mosquitoes can zero in on an unlucky camper by following the scent of the carbon dioxide he breathes out. From 3 meters away, mosquitoes can detect the heat from his blood. Like leaches and ticks, most parasites have either sucking mouthparts or hooklike appendages that keep them attached to their hosts. Many parasites—especially internal parasites—don't leave once they find a good host to exploit. They do, however, face a tough challenge in finding a new host for their offspring (after all, an intestine can only hold so many tapeworms). To increase the odds that at least a few of their young will survive, most parasites produce a staggering number of offspring. It's been estimated that a single liver fluke can produce four hundred million offspring over its lifetime. Many parasites have elaborate life cycles that involve several intermediary hosts before the offspring wind up in their final host. For example, the protozoan responsible for causing malaria in humans spends part of its life in the saliva of mosquitoes.



Desmodium seeds, or stick-tights, latch on to whatever brushes against them—feathers, fur or clothing.

Ted Bodner, Southern Weed Science Society, Bugwood.org

Commensalism benefits one organism but does not affect another.

Watch a herd of cattle grazing on a pasture, and you might notice a little brown bird hopping through the grass at their feet. The bird, called a brown-headed cowbird, can be found in grasslands throughout the Midwest, wherever there are cattle or bison. The reason they stick close to cattle is simple—cowbirds are looking for an easy meal. As cattle move from plant to plant, they stir up insects, which become easy prey for the cowbirds. In this relationship, the cowbirds benefit from their interaction with the cattle. The cattle, however, are neither harmed nor benefit, and are mostly unaffected by the cowbirds. Ecologists call this kind of interaction—where one organism benefits and the other is unaffected—**commensalism**.

If you've ever walked through a weedy field in the fall you've probably been an unwitting participant in an act of commensalism. *Desmodium* is a plant that has seeds covered with a Velcro-like substance. The seeds, or sticktights, latch on to whatever brushes against them. Although they are a hassle to pick off clothing, the seeds don't really harm you

or the animals they stick to. *Desmodium*, however, benefits from the interaction by having its seeds carried away from the parent plant. This lowers the chance the offspring might compete with the parent for water, nutrients and other resources.

Ecologists differ on what they consider commensalism. Some ecologists think commensalism should include any instance where one organism benefits and another is unaffected. In this view, a robin nesting in a maple tree is a commensal interaction, because the robin benefits from the shelter the tree provides, while the tree is unaffected by the robin's nest. Other ecologists only consider an interaction to be commensalism when the benefiting organism cannot survive without the other species. In this narrower view of commensalism, because the robin can nest in many different kinds of trees, the relationship between the bird and the maple is not commensal. If, however, robins relied solely on maple trees to hold their nests, then the relationship would be an example of commensalism. Some ecologists believe that pure commensalism does not exist at all. These ecologists argue that any close relationship has to be slightly beneficial or harmful to the organism originally thought to be unaffected. Take, for instance, the relationship between cowbirds and cattle. Some ecologists would point out that by eating insects that parasitize cattle, cowbirds actually help the cows. When looked at from this point of view, both organisms benefit, a type of interaction called mutualism.

Mutualism benefits each organism that participates in the interaction.

Many interactions between organisms benefit both participants. Bees disperse a flower's pollen in return for a meal of nectar. The bacteria living in a rabbit's gut break down and release energy from cellulose. In return, the microorganisms get a steady supply of food and a warm place to live. Fungi living on the roots of an oak tree help the tree gather nutrients from the soil. The tree uses the nutrients to build sugars, which it shares with the fungi. In each of these relationships, both participants benefit, a situation ecologists call **mutualism**.

Mutualism can benefit the participants in different ways. Mutualism can help participants gather food and energy more efficiently. Lichens, those mossy-looking organisms that grow on rocks and bark, are actually two separate organisms. One is a fungus that specializes in gathering nutrients from the surface on which it grows. The other is an algae that specializes in turning sunlight into usable energy. The fungus provides the algae with nutrients for photosynthesis, and the algae provide the fungus with energy. The relationship between herbivores and the microorganisms in their guts also fall into this category of mutualism.

A bumblebee transports pollen from one flower to another as it gathers nectar.

Russ Ottens, University of Georgia, Bugwood.org

Mutualism can help one of the organisms reproduce. Ever wonder why blackberries often grow along a fence? It's because birds eat blackberries, which contain seeds. Some of these seeds pass through the birds' guts undigested. Birds use fences for perches and leave droppings containing undigested seeds along the fence row. In this relationship, the bird gets a sugary meal, and the blackberry gets its seeds dispersed with the droppings as fertilizer. Many fruit-bearing plants disperse seeds in this manner. Pollinators and nectar-producing plants are another example of this category of mutualism.

Mutualism can increase the safety of the participants. Remember Müllerian mimicry, when dangerous or noxious organisms display similar colors and patterns, such as bees and wasps that all have black and yellow stripes? If a predator gets stung by

Type of Interaction	Examples	Outcomes for the Organisms Involved
Competition	Intraspecific	Lose/Lose
	Interspecific	Lose/Lose
Exploitation	Predation	Win/Lose
	Herbivory	Win/Lose
	Parasitism	Win/Lose
Commensalism		Win/No Effect
Mutualism		Win/Win

Table 4.1—Interactions Among Organisms ***(Blue shading indicates symbiosis.)***

one species in this group of mimics, it learns to avoid the other species in the group. By looking like each other, all the bees and wasps are safer than if each looked different.

When two organisms have such a close relationship that one could not survive without the other, ecologists refer to the partnership as **symbiosis**. Rabbits could not gather enough nutrients from the plants they eat without the help of microorganisms in their digestive tracts. Tapeworms could not survive without a host to live in. *Desmodium* could not disperse its seeds without the help of furbearers and humans. These examples show that mutualism, parasitism and some kinds of commensalism are all types of symbiosis. Table 4.1 summarizes the types of interactions we've explored in this chapter.

Interactions maintain balance within ecosystems.

Are interactions important? Yes. To prove it, let's remove a few examples of mutualism from the biosphere and see what happens. Without microorganisms to break down cellulose, most herbivores would soon die of malnourishment. This would hardly matter, though, because without fungi to help gather nutrients, nearly 90 percent of all plants on earth would die. With herbivores gone, the predators that eat them couldn't find enough food. Without flowering plants, pollinators such as hummingbirds, honeybees and butterflies would die. With many food supplies gone, humans would soon perish, too. The loss of mutualistic relationships would ripple through the biosphere until very few organisms remained. From this we can see just how important mutualistic interactions are.

Mink and muskrats provide another example of the importance of interactions. Mink are one of the primary predators of muskrats. If we were to compare the population sizes for mink and muskrats

The interactions between mink (left) and the muskrats they prey upon help maintain balance in wetland ecosystems.

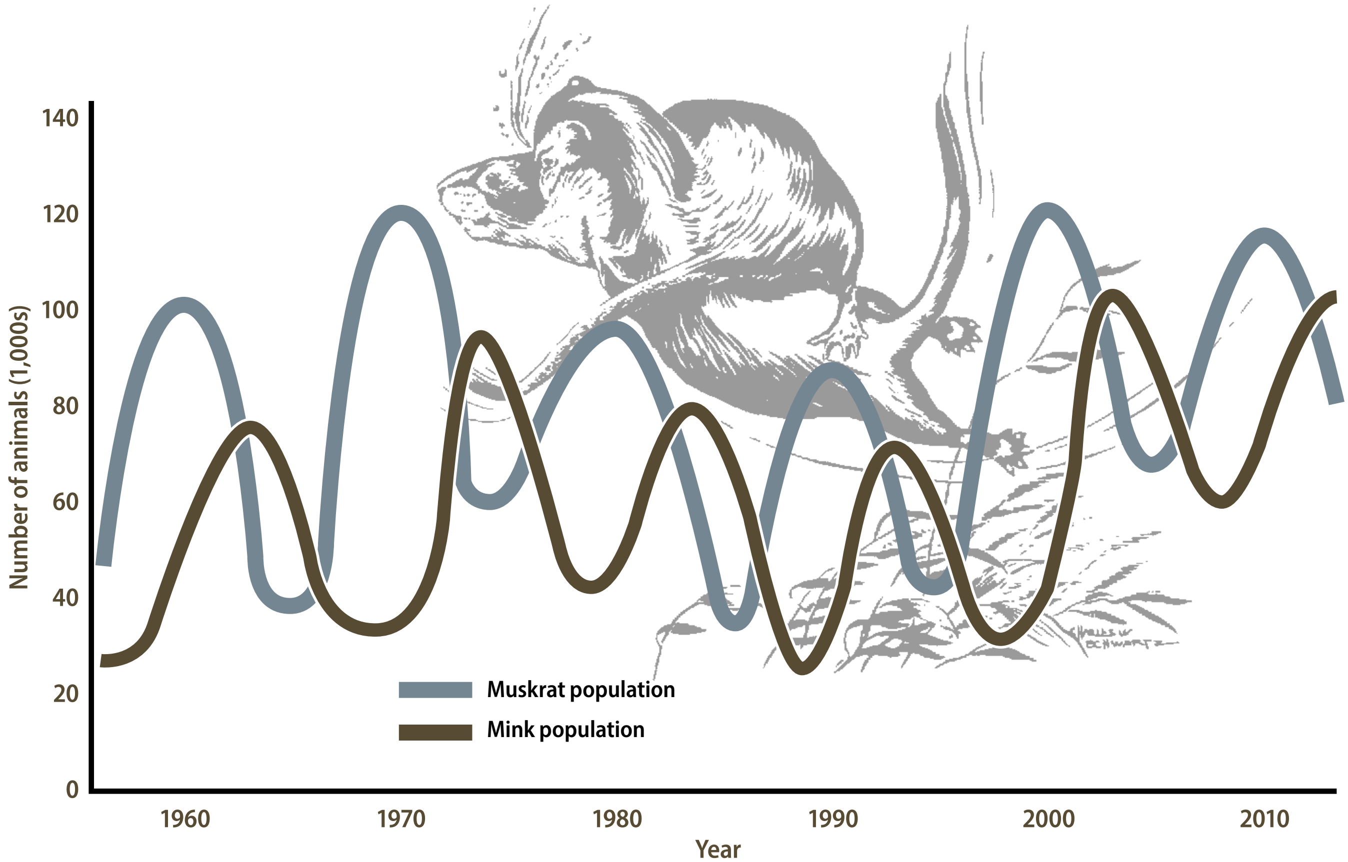


Figure 4.4—The peaks and valleys in the size of a mink population are influenced by the shortage or abundance of their prey, muskrats. Likewise, the peaks and valleys in a muskrat population are influenced by the abundance of mink. This pattern is typical of many predator-prey cycles.

(Figure 4.4), we would notice something interesting. About every 10 years the muskrat population reaches a peak, but then quickly plummets. Likewise, the mink population seems to grow and shrink on the same 10-year cycle, with one key difference: the mink population peaks and plummets about three years after the muskrat population. Why? When there are few mink, the muskrat population grows quickly. With more muskrats to eat, the mink population also begins to grow. Eventually the mink population begins to consume muskrats faster than the muskrat population can reproduce, and the muskrat population quickly shrinks. Without enough muskrats to eat, the mink population soon declines. This sequence results in a series of peaks and valleys in the population sizes of both mink and muskrats. Ecologists call these population fluctuations **predator-prey cycles**.

Predator-prey cycles affect more than just the organisms directly involved. Muskrats use aquatic vegetation for food and to build their lodges. Too many muskrats can consume all the vegetation in a marsh. While this is terrible for the cattails, bulrushes and arrowhead plants, it's equally bad for the marsh wrens that nest in cattails, the waterfowl that eat seeds produced by the plants, and the entire community of wetland organisms that depend upon marsh plants for food or shelter. Many of the organisms that eat plants are prey for other species. When prey disappears, predators soon decline. By keeping prey populations in check, predators help maintain balance in an ecosystem. ▲

Huge flocks of Carolina parakeets were a common sight when Lewis and Clark passed through Missouri in the early 1800s. By 1914, the colorful bird had been pushed to extinction by loss of habitat and unregulated hunting.

BIG IDEAS:

- Extinction is part of nature.
- There have been at least five mass extinctions in the past, and humans are likely causing a sixth.
- Extinctions occur when species fail to adapt to changing ecological conditions.
- Some species are more prone to extinction than others.
- Extinction has consequences.

EXTINCTION: Causes AND Consequences

Tuesday, June 26, 1804—It had been a trying day for the Corps of Discovery. After miles of rowing their keelboat upstream, the 12-ton vessel had become hopelessly beached on a sandbar. Fearing she might tip sideways and take on water, Captain William Clark ordered his men into the river to pull the boat free. The crew struggled for hours—and snapped two tow ropes—but eventually dragged the boat into deeper water. His men exhausted, Clark halted the expedition just a mile upstream. As the crew made camp near present-day Kansas City, Clark penned in his journal, "I observed an immense number of parakeets this evening."

Although one might attribute Clark's parakeet sighting to fatigue, the explorer was not hallucinating. Carolina parakeets were once common in forests from Virginia to Nebraska. With flashy green bodies, yellow heads and bright orange cheeks, the birds were unmistakable. About the size of a blue jay, the parakeets formed enormous, noisy flocks and were notorious for swarming crop fields and fruit orchards.

Lewis and Clark's expedition marked the beginning of the end for the parakeet. Settlers followed the explorers westward, cutting down huge expanses of forest to clear space for crops. Farmers considered the bird a pest and slaughtered them by the thousands. Hunters also shot huge numbers, shipping the birds' bright feathers east where they were used to decorate ladies' hats. Pushed into ever smaller blocks of habitat and hunted by nearly everyone who owned a gun, parakeet populations plummeted. By 1870, Carolina parakeets were gone from Missouri. In 1904, the last parakeets in the wild disappeared. In September, 1914, the last Carolina parakeet on Earth died at the Cincinnati Zoo, marking the extinction of one of North America's most colorful birds *(Figure 5.1)*.

Extinction, or the complete elimination of an entire species, is the harshest reality of nature. Extinction cannot be undone—extinction is forever. In this chapter, we will investigate what causes extinction, compare past extinctions to recent ones, and examine the role humans play in the extinction of other species.

Extinction is part of nature.

Carolina parakeets, woolly mammoths and tyrannosaurs are just a few of many species that have vanished from Earth. In fact, fossil records reveal 99.9 percent of all species that ever lived are now extinct. This reveals that extinction isn't the unlikely fate of a few unlucky species, but rather a natural process that most species are likely to face. Before we examine what causes extinction, it will be useful to distinguish between several types of extinction.

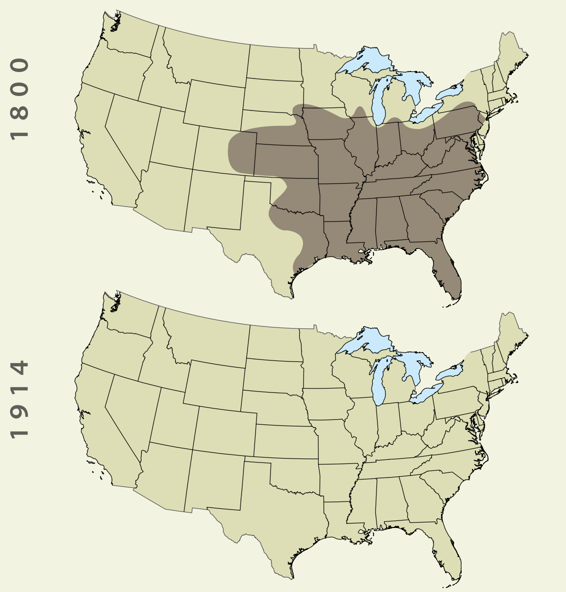


Figure 5.1—In the early 1800s, Carolina parakeets were common in forests from Virginia to Colorado (top). By the early 1900s, the parakeet had been completely eliminated from forests throughout the United States (bottom). In 1914, the last Carolina parakeet on Earth died, marking the species' extinction.

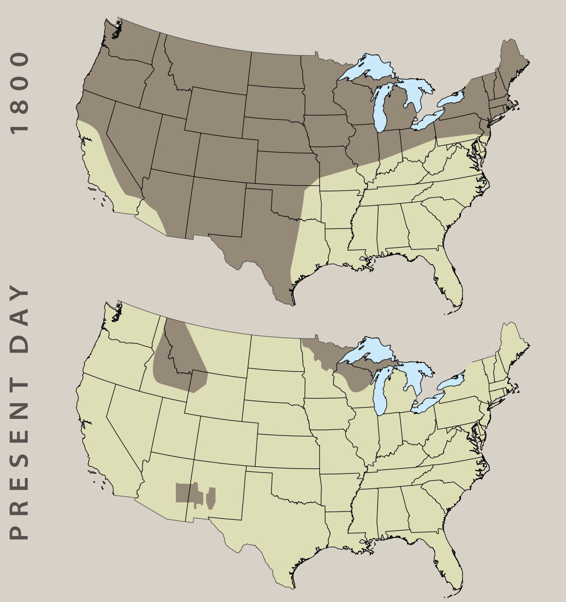


Figure 5.2—Before European settlement, gray wolves ranged throughout much of the United States (top). Wolves have since been extirpated from most of their historic range, but small populations still exist in several states such as Minnesota, Montana and New Mexico (bottom).

While camped at present-day Kansas City, the Corps of Discovery crew went hunting. According to Private Joseph Whitehouse, "The hunters killed five deer, one wolf and caught another about five months old. We kept it for three days. Cut its rope. Got away." As Whitehouse indicates, gray wolves once prowled northern Missouri. By the early 1900s, over a century of unrestricted hunting had eliminated them from the state. Although gone from Missouri, healthy wolf populations still exist in other places, such as Minnesota, Montana and Alaska. Ecologists use **extirpation** to refer to these local extinctions, when a species disappears from one location but survives in another.

As ecosystems change, some species disappear and others take their place. This **natural** or **background extinction** can be caused by several things. Some species cannot adapt quickly enough to keep pace with environmental changes. Others cannot survive predation from or compete with new species that show up. Some species are just in the wrong place at the wrong time and fall victim to chance catastrophes like fire, storm or disease.

Background extinction occurs at a relatively slow pace. By examining the fossil record, ecologists have found species generally exist for about one to 10 million years. Put another way, for any given year, a particular species has between a one in a million and a one in 10 million chance of going extinct. Earth likely contains between one and 10 million species. Thus, ecologists estimate background extinction should occur at a rate of one species per year.

Most ecologists believe current extinction rates are far higher than the expected background extinction rate. Just how many species disappear each year, however, is hotly debated. The renowned Harvard ecologist E.O. Wilson has calculated an extinction rate of 30,000 species per year. If his estimate is right, in the time it takes this class period to end, three to five species will have disappeared from Earth. Other estimates range from a few thousand to more than 100,000 species disappearing each year. Regardless of the actual number, the current extinction rate is cause for concern. In fact, ecologists believe we are in the midst of a **mass extinction**, the dying off of a large number of species in a relatively short span of time.

There have been at least five mass extinctions in the past, and humans are likely causing a sixth.

Late in the Cretaceous Period, about 65 million years ago, a *Tyrannosaurus rex* lifts its blood-splattered head from the carcass of a duck-billed dinosaur. A bright flash, like an enormous bolt of lightning, has caught the eye of the toothy scavenger. Seconds later, the ground shudders from some distant, but massive impact, and the T-rex lumbers toward the safety of a grove of palm trees. Then, the sky goes black.

Within a few hundred thousand years, Tyrannosaurs and most other dinosaurs had vanished. In fact, over half of Earth's species perished during this time. Many scientists believe that an asteroid (or maybe several) collided with Earth near present-day Mexico, kicking up a global cloud of dust that blotted out the sun. Scientists theorize this created a decade-long winter that led to the collapse of entire ecosystems.

Other scientists offer alternative explanations. About this time, a supercontinent called Pangea was breaking apart into the smaller continents we recognize today. As pieces of Pangea shifted, they altered ocean currents and climate patterns, creating a period of global cooling. Continental shifting also triggered the eruption of the Deccan Traps, a chain of immense volcanoes in India. These super volcanoes spewed out vast amounts of lava and belched climate-altering gases, further contributing to Earth's global cooling. Life could not adapt quickly enough to this rapid cooling, and over half the world's species disappeared. According to this theory, the asteroid was nothing more than the final nail in the dinosaurs' coffin.

The series of die-offs at the end of the Cretaceous marked the most recent mass extinction in Earth's history. By studying fossil records and other geological evidence, scientists have found proof of four other mass extinctions *(Figure 5.3)*. There have probably been others. Although the cause of each mass extinction isn't completely understood, physical forces, such as falling sea levels, climate change or volcanic eruptions, are likely to blame.

The first mass extinction we know about occurred 445 million years ago. Nearly all life lived in water at this time. Scientists believe Pangea slowly drifted over the South Pole, causing glaciers to form, which pulled water from the oceans. Sea levels dropped worldwide—a possible cause of the disappearance of 57 percent of Earth's species.

The second mass extinction occurred about 370 million years ago. As plants adapted to life on land, they began removing large quantities of carbon dioxide from the

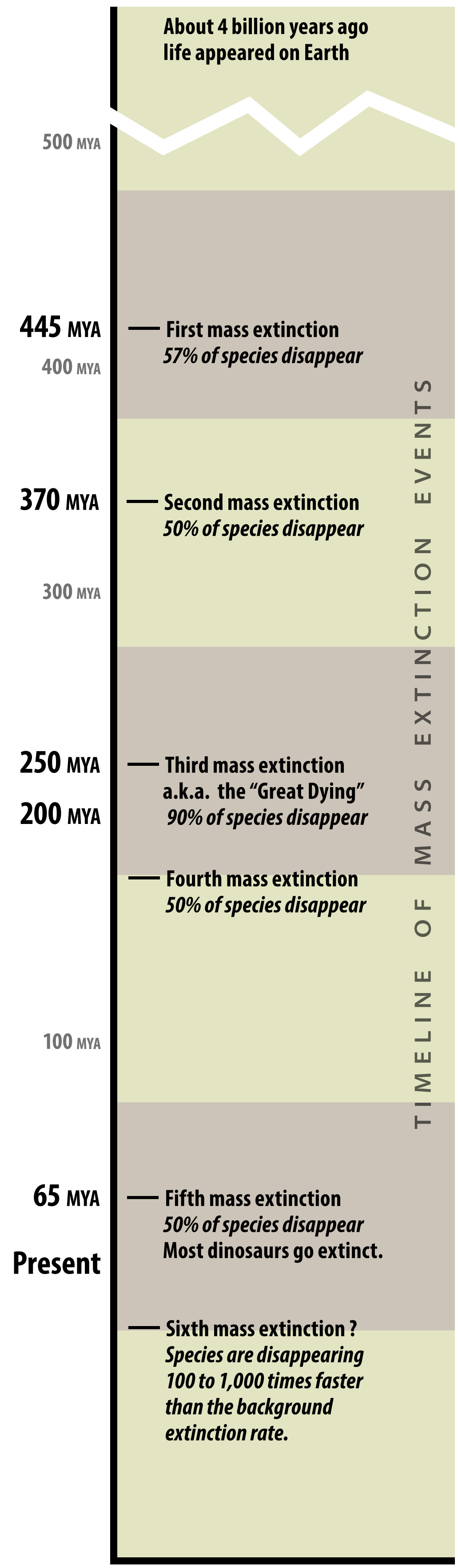


Figure 5.3—Timeline of Earth's Mass Extinctions
(MYA - Million Years Ago)

atmosphere. This created a reverse greenhouse effect, causing the Earth to cool. Cooling temperatures fostered the formation of large land glaciers. This created a drop in sea levels, and thousands upon thousands of reef-building corals and shallow marine organisms—over 50 percent of Earth's species—perished.

Earth's third mass extinction occurred about 250 million years ago. This was the big one—the closest life has ever come to ending. Known to scientists as the "Great Dying," 96 percent of sea life disappeared and 70 percent of all land vertebrates perished. All told, more than 90 percent of Earth's species were wiped from the planet. Many events likely contributed to a mass extinction of this scale. Scientists have found evidence of colossal volcanic eruptions, some of which lasted hundreds of thousands of years. In addition, Pangea was on the move again. This time, its change in position likely altered ocean currents. Both events, along with a possible meteor strike, cooled the Earth to the point where most life ceased to exist.

The fourth mass extinction wiped out more than 50 percent of Earth's species alive at the time. The likely cause was the eruption of a chain of volcanoes in the Atlantic Ocean. Every few centuries, these mega-volcanoes spewed out millions of cubic kilometers of lava and belched quadrillions of kilograms of sun-blocking sulfur. This resulted in a roller coaster of global cooling and warming, and many species couldn't survive the ride.

Earth is in the middle of a sixth mass extinction. In Missouri, conservationists are concerned about more than 600 kinds of plants and more than 300 kinds of animals because their numbers are extremely low or declining rapidly. According to data compiled by the World Conservation Union, 12 percent of Earth's birds, 20 percent of its mammals and 31 percent of its amphibians are **endangered**, or at risk of going extinct in the near future. Ecologists estimate species are disappearing 100 to 1,000 times faster than the expected background extinction rate.

The current mass extinction is unlike any that have occurred previously. Evidence indicates that past mass extinctions were caused by abiotic forces such as volcanic eruptions, asteroid collisions, shifting continents and changes in sea levels. In contrast, most scientists agree that today's mass extinction is directly or indirectly caused by biotic forces, namely human beings. To understand the role humans play in this sixth mass extinction, we need to examine the causes of extinction.

Extinctions occur when species fail to adapt to changing ecological conditions.

Why do species go extinct? In the broadest sense, extinction is a result of natural selection—species disappear when they fail to adapt to changing ecological conditions. In more specific terms, species disappear when deaths exceed births over a long enough period. Thus, any process that lowers birth rates or increases death rates can cause a species to go extinct. Such forces may act independently or team up on a species to bring about its demise. Ecologists pin current extinction on four primary causes, each of which is directly or indirectly influenced by the actions of humans.


Human development, such as subdivisions, can fragment large blocks of habitat into smaller, scattered pieces.

Habitat Destruction

Habitat destruction and **fragmentation**, the carving of large blocks of habitat into smaller, scattered pieces, are the biggest threats to most species. Without adequate habitat in which to grow, survive and reproduce, births decrease, deaths increase, and it isn't long before species goes extinct.

Invasive Species

Wherever humans have traveled, we have accidentally or deliberately brought other species with us. Non-native species like European starlings, emerald ash borers, zebra mussels and sericea lespedeza are often invasive, adapting quickly to new locations and pushing out native species. Invasive species do this by altering habitats, competing for limited resources or preying directly upon native species.

Overexploitation

Some organisms are hunted, fished or harvested to extinction. Technology has provided humans with tools, such as firearms, nets and chainsaws, that many species cannot defend against. When we use these tools without restraint, we can cause species to go extinct.

At one time, passenger pigeons were the most abundant bird on the planet. The naturalist John James Audubon watched a flock pass overhead for three days and estimated that 300 million birds flew by each hour. Passenger pigeons had two traits, however, that brought about their demise: they tasted good and they were easy to kill. To supply meat to expanding cities, hunters fired into the enormous flocks, killing dozens of birds with each shot. Pigeons were baited with alcohol-soaked grain that made them drunk and easy to catch. Some hunters clipped the wings of captive pigeons and used them as live decoys. During the height of the pigeon slaughter, hunters killed nearly 400,000 pigeons each month in Michigan alone. In 1914, the last surviving member of a species that once numbered 5 billion strong died at the Cincinnati Zoo.

Climate Change

Every organism is adapted to live within a particular range of environmental conditions. If abiotic factors such as temperature, precipitation or oxygen concentration shift outside the range required by a particular species, the existence of that species in that particular habitat becomes impossible. Changes in global temperatures have wide-ranging effects on environmental conditions and are expected to cause population declines in species ranging from tropical corals to Midwestern mammals.

Many scientists believe that human activities, such as the burning of fossil fuels, are contributing to increases in global temperatures. Other scientists dispute this claim, arguing that temperature increases are part of Earth's natural climate cycle.

European starlings are aggressive birds that compete with native species for nest sites and other resources.

Market hunters drove passenger pigeons to extinction and nearly wiped out many other species.

Many scientists believe burning fossil fuels, such as coal, contributes to increasing global temperatures.

Battling Exotic Invaders

To most, exotic brings to mind something unique, rare and beautiful. To a resource manager, exotic means something completely different. **Exotic**, **non-native** or **introduced** species all refer to an organism that has moved into an area in which it previously did not exist. Scientists estimate that over the past century close to 4,500 exotic plants and animals have moved into North America. While some, like the honeybee, have been beneficial, others have wiped out native populations and devastated local ecosystems. Resource managers refer to these species as **invasive** because they spread rapidly and harm native organisms.

Most invasive species grow quickly, reproduce often and bear many offspring. Limiting factors that keep them in check in their original environments, such as predators, competitors or disease, may not be present in their new locations. Native organisms rarely have adaptations to compete with invading species or fend off their attacks. As a result, the native organisms are often displaced or go extinct. Invasive species disrupt ecosystems, damage agricultural crops, and spread disease to native and domesticated plants and animals. An ever-increasing part of resource management is stopping the spread of these unwanted plants and animals. Here are a few of Missouri's worst invasive species and what managers are doing to stop their spread.

There's a killer loose in Missouri's forests.

A centimeter-long, metallic green beetle called the emerald ash borer has killed more than 50 million ash trees throughout North America. The beetle's wormlike larvae feed on tissues under the bark of ash trees. Over time, this cuts off the tree's supply of water and nutrients, and the tree eventually dies. No ash is safe from this tiny but destructive pest, and scientists are worried it could wipe out all of North America's ash trees.


Emerald ash borers kill ash trees.

Although scientists aren't sure exactly how the insect arrived in the United States, it most likely hitched a ride in wooden packaging materials, such as crates or pallets, shipped from Asia. Although adult beetles rarely fly far from the tree where they hatch, both adults and larvae can hitchhike long distances in firewood. This is likely how emerald ash borer ended up in Missouri.

To date, a cost-effective way to eradicate emerald ash borer has not been found. Pesticides have been developed that will kill the insect, but they are not safe, practical or economical to use over a widespread area. Instead, managers are working hard to slow the beetles' spread. Scientists survey forests, parks and other areas to detect new outbreaks, and inspectors perform regular checks on nurseries and lumber mills. If an infestation is found, managers set up quarantines and enforce laws to prevent the removal of ash logs, nursery trees and firewood from the area. Ads and radio announcements are used to educate the public about the threat of emerald ash borer and the danger of moving firewood. In Asia, scientists have observed parasitic wasps attacking emerald ash borer eggs and larvae. Efforts are underway to determine if these wasps could be safe and effective to control emerald ash borer in North America.

A mini-monster is "musseling" into Missouri's waterways.

A fingernail-sized mollusk is taking over waterways across North America. Zebra mussels, which look like black-and-white striped clams, are native to the Caspian Sea. They were transported to North America in the bilge water of ships and first discovered in waters near Detroit in 1988. Since then, these invasive mussels

Zebra mussels, shown here attached to a native mussel, compete with native species for food and living space.

have spread rapidly throughout the Great Lakes, worked their way into the Mississippi and Missouri rivers, and turned up in several Missouri lakes.

Female zebra mussels can produce 1 million eggs each year. These develop into free-swimming larvae that disperse with currents, settle onto firm surfaces and quickly form dense colonies. At a power plant on Lake Erie, zebra mussels went from undetectable levels in 1988 to 700,000 per square meter in 1989.

Zebra mussels feed on plankton, the microscopic plants and animals that form the basis of the aquatic food chain. This puts them in direct competition with native mussels and young fish, including bass and bluegill. Zebra mussels can blanket native mussel colonies and prevent them from getting nutrients. Large colonies of zebra mussels can remove enough oxygen from the water to cause fish kills. Removing zebra mussels from boats, docks and water intakes is expected to cost billions of dollars over the next decade.

Zebra mussels spread to new water by hitching rides on boats, trailers and other marine equipment. Resource managers are urging people to keep zebra mussels from spreading by washing their boats and trailers with hot water between trips and letting them dry in the sun for at least five days. This will kill any zebra mussels that might be attached.

This plant won't stay put.

Once called "poor man's alfalfa," sericea lespedeza was initially introduced to the United States from eastern Asia as a pasture crop. It first appeared in Missouri in the 1930s, when it was planted for livestock forage, erosion control and wildlife food. Since that time, both livestock producers and resource managers have realized sericea's disadvantages far outweigh its possible benefits.

Wildlife, such as quail, will eat sericea seeds, but are unable to fully digest them because of the hard outer shell. Cattle only eat the tender new growth of young sericea plants because the mature plant is too tough. When mature, sericea is tall and dense enough to block sunlight from other plants. It also saps water from the soil, and its roots produce chemicals that hinder the growth of other plants. Once it gains a foothold, sericea quickly overtakes an area, crowding out all other plants.

Sericea lespedeza crowds out native plants and provides little for wildlife.

A single stem of sericea can produce more than a thousand seeds. Because its seeds float, the plant spreads easily throughout watersheds. Birds and other animals also distribute the seeds. Fortunately, sericea is fragile during its seedling stage and slow to establish. Unfortunately, once established, it's tough to get rid of.

Resource managers scout public lands across the state to keep tabs on sericea. When found, managers try to eradicate the plant using a combination of burning, mowing and herbicide application. Since sericea seed can stay viable in the soil for many years, repeated treatments are needed to completely eradicate an established population. Researchers are currently working on quicker, easier and cheaper ways to get rid of this pesky plant.

Restoring Grasslands, Saving Birds

A biological crisis is unfolding across America's Great Plains. Populations of grassland birds are disappearing from many areas and declining at an alarming pace in others. Breeding bird surveys conducted by biologists and birdwatchers throughout the country reveal that of the 42 grassland birds monitored annually, 23 are showing significant population declines. The surveys also show that, as a group, grassland birds are declining faster and more consistently than birds in other ecosystems, such as wetlands or forests. Some of America's best-known birds, such as meadowlarks, bobwhite quail and prairie-chickens, have declined by 38 to 77 percent since 1968.


Eastern meadowlark

Such staggering losses illustrate the effect of limiting factors. Each kind of grassland bird has a unique list of habitat requirements that must be met for it to survive and reproduce. When grasslands are plentiful, those requirements are met. When grasslands disappear, those requirements aren't met, and the lack of habitat acts as a limiting factor.

In the early 1800s, prairies covered more than a third of Missouri, or 6 million hectares. Today, less than 1 percent—just 30,000 hectares—remains. Native prairies support more than 200 kinds of grasses and wildflowers, providing birds a buffet of food, nesting sites, places to raise chicks and cover to escape from predators. Grassy fields today often contain only one type of plant, a non-native grass called tall fescue. Without the diversity provided by native prairies, grassland birds have a tough time finding the things they need to survive and reproduce. Although birds may use these crop fields, golf courses and pastures, haying, grazing and frequent disturbance by people can create **population sinks** where birds try to nest but fail to raise their young.

While loss of grassland habitat is the primary limiting factor, others also play a role. The increased use of pesticides and herbicides can be toxic to birds or kill the insects and weeds they feed on. Feral cats and hogs eat adult birds or their eggs. Droughts and loss of wintering habitat in Central and South America contribute to declines.

The situation isn't hopeless. In the 1970s, wetland birds faced a similar crisis. Today, many wetland birds are showing an upward trend. The key to this reversal of fates has been coordinated efforts by government agencies, nonprofit groups and private landowners to protect and restore millions of acres of wetland habitat. Resource managers and private landowners are using this as a model for reversing the downward spiral of grassland bird populations. Here are some of the things they're doing:

- Federal, state and nonprofit agencies along with private landowners are restoring native prairies throughout the state. This involves eradicating non-native vegetation in an area and reseeding the ground with native grasses, wildflowers and shrubs.
- Many row crop farmers are taking advantage of incentives offered in the federal Farm Bill that pay landowners to leave weedy borders around the edge of their corn, soybean and wheat fields. These borders provide much-needed habitat for grassland birds.
- An increasing number of cattle farmers are converting their pastures from nonnative grasses that don't benefit wildlife to native prairie grasses that do. The prairie grasses provide an excellent food for cattle and great habitat for birds. Landowners are encouraged to hold off haying these pastures until after nesting season, giving birds a chance to hatch and raise their young.
- If left alone, prairies in Missouri soon become covered with shrubs and trees. Before settlement, trees were kept at bay by grazing herds of bison and elk or fires set by lightning or Native Americans. Nowadays, resource managers try to recreate these natural disturbances by grazing cattle, using mowers and disks, and setting prescribed fires.

Some species are more prone to extinction than others.

Why do some species, like Carolina parakeets, go extinct, while others, like cockroaches, survive for eons? It turns out that certain traits make some species more prone to extinction than others.

One way ecologists group species is based on the range of habitats and environmental conditions in which they can survive. Some, like white-tailed deer, can live in many kinds of habitats and survive a wide range of environmental conditions. Ecologists call these kinds of species **generalists**. Put another way, generalists have a broad niche. In contrast, species like Indiana bats that hibernate in just a few caves throughout the Midwest and that survive in only a narrow range of environmental conditions are called **specialists**. Specialists have a narrow niche. Because their niche requirements are more difficult to meet, specialists are more prone to extinction than generalists.

All else being equal, small populations are more likely to go extinct than large populations. Consider your bank account. If you have $1,000 in your account, losing $5 has little effect. If, however, you have only $10 in your account, losing $5 means you've lost 50 percent of your savings. Deaths affect small populations in much the same way. Because they have less genetic variation and are thus less able to adapt, small populations are more likely than large populations to be wiped out by disease, parasites and changing environmental conditions. Small populations often possess less genetic variation than large populations because of **inbreeding**, which occurs when two closely related individuals mate and produce offspring. And, a phenomenon known as the **Allee effect** can draw small populations toward extinction by affecting behaviors that depend on high population densities. For example, when population densities are low, it may be hard for individuals to find mates (which affects births) or group together in herds, flocks or schools for defense (which affects deaths).

White-tailed deer are considered generalists because they can live in a variety of habitats. Because they have strict habitat requirements, Indiana bats are considered a specialist species.

In general, species that inhabit a large geographic area are less likely to go extinct than species that inhabit a more restricted geographic area. Extensive geographic ranges offer a buffer against environmental change. Therefore, if environmental conditions change and kill off populations in one area, populations of the same species in other areas can still survive.

Taken together, niche tolerance, population size and geographic range help ecologists predict whether or not a species is prone to extinction. As shown in Figure 5.4, there are eight possible combinations of these factors. Species that are least likely to go extinct are generalists with large populations that have extensive geographic ranges. In contrast, species most likely to go extinct are specialists with small populations that occupy restricted geographic ranges.

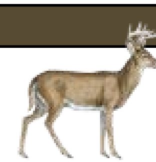
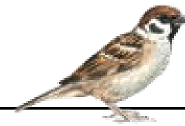
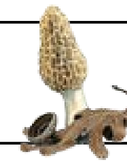
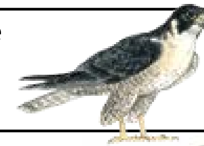
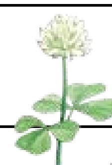
Risk of Extinction	Traits	Examples
 LOW	Generalist Large population Extensive range	White-tailed deer 
	Generalist Large population Restricted range	Eurasian tree sparrow 
	Specialist Large population Extensive range	Morel mushroom 
	Generalist Small population Extensive range	Peregrine falcon 
	Specialist Large population Restricted range	Niangua darter 
	Generalist Small population Restricted range	Running buffalo clover 
	Specialist Small population Extensive range	Indiana bat 
HIGH	Specialist Small population Restricted range	Ozark cavefish 

Figure 5.4—There are eight possible combinations of niche tolerance, population size and geographic range. These factors help predict how prone a species is to extinction.

Extinction has consequences.

Why should we care whether or not a species goes extinct? For many, extinction is a moral issue. Because humans have destroyed habitats, introduced invasive species, over-harvested populations and possibly contributed to climate change, many people believe it is our moral responsibility to correct these problems and save species from extinction.

In addition, many species provide economic benefits to humans. Some plants and animals are important food resources. Others, like trees, provide products such as lumber, paper and rubber. Several medicines, including anesthetics important for pain relief, are derived from flowering plants. Many people enjoy hunting, fishing or nature viewing and pay money to do so.

The greatest risk of extinction, however, relates to the role each species plays in a biological community. As we learned in chapter four, species maintain balance within communities by keeping other populations in check through competition, exploitation and mutualism. Large predators, such as wolves and mountain lions, have been extirpated from Missouri and many other areas of the country. In many ecosystems, human hunters have taken over as the major predator keeping prey populations in check. But, in areas without large predators—human or otherwise—prey populations can skyrocket and cause problems. For example, too many white-tailed deer in a forest can create browse lines where every scrap of vegetation

is eaten from the ground to as high as a deer can reach. This affects not only the plants the deer have eaten, but also animals that rely on those plants for food and shelter. In the end, it even affects the deer themselves, because many deer eventually starve when food runs out.

One might argue that not every species plays a major role in an ecosystem. The extirpation of white-footed mice from a forest would probably have little effect on the forest community. Other species, such as deer mice and woodland voles, have similar niches and play similar roles. If several of these small mammal species are extirpated, however, species that prey upon them, such as snakes, hawks, bobcats and foxes, also begin to dwindle. A community is a bit like an automobile in this regard. Like a biological community, an automobile has thousands of major and minor parts that keep it running. Lug nuts, for example, secure the wheels of an automobile to the axle. Most vehicles have four to eight lug nuts on each wheel. This way, if one falls off, others remain to hold the wheel in place. If several are lost, however, it isn't long before the wheel falls off and the car crashes. In the same way, if too many species go extinct or are extirpated from a community, it isn't long before the community crashes.

In the chapters that follow, we'll expand our exploration of the role species play in communities and ecosystems. We'll learn how energy flows through communities, how elements cycle through ecosystems and what factors influence the amount and variety of species that live in an area. We start this exploration in Chapter 6 by examining how energy from the sun is transferred through food chains and food webs. ▲

The extirpation of white-footed mice probably would have little effect on a forest community. If several small mammals were extirpated, however, predator populations, such as snakes, would soon dwindle. And, if too many species were extirpated, it wouldn't be long before the community crashed.

Missouri's wetlands produce more life than nearly any other place on Earth. Only tropical rainforests and coastal salt marshes yield more life per square meter.

BIG IDEAS:

- Organisms need energy to grow, survive and reproduce.
- Most organisms obtain energy through photosynthesis or by eating other organisms.
- Primary production is affected by temperature, moisture and nutrients.
- Food chains show a specific pathway of energy flow in a community.
- Food webs are complex illustrations of interconnected food chains.
- Some species affect a food web more than others.
- Energy pyramids simplify food webs by sorting organisms into trophic levels.
- Only about 5 to 20 percent of energy passes from one trophic level to the next.

EXPLORING THE Nature OF ENERGY FLOW

Life squishes out from every soggy corner of a wetland. Red-winged blackbirds whistle from bulrushes growing at the water's edge. A falcon swoops like a feathered missile toward a flock of feeding ducks. Atop a muskrat lodge, a water snake lies motionless, soaking in the sun's warm rays. Nearby, a marsh wren takes time out from foraging for insects to scold the snake. Tadpoles swirl in the shade of an arrowhead plant, avoiding deeper water where sunfish and bullheads lurk. A river otter swims sinuously by, ignoring the tadpoles—it's hunting bigger game. Bullfrogs bellow, bitterns croak and everywhere is the hum of insects.

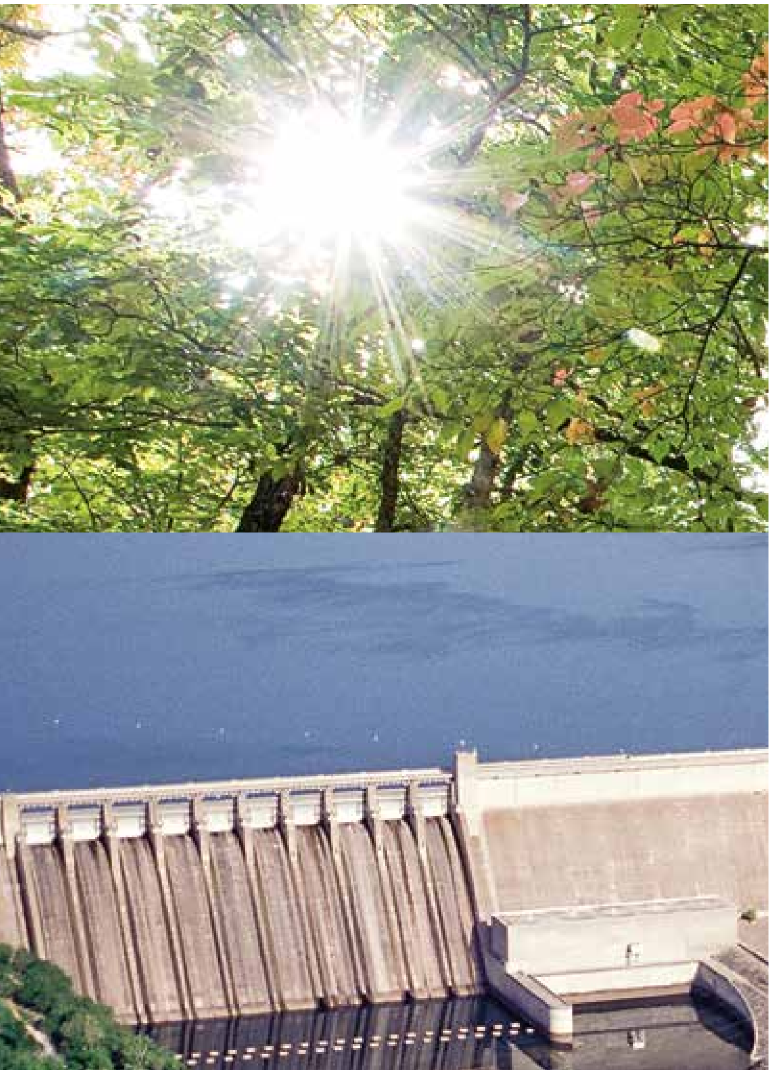
Hectare for hectare, Missouri's wetlands rival any place on the planet in the amount of life they produce. Nearly half of Missouri's 3,200 plant species are associated with wetlands, and more than a third of Missouri's birds depend on wetlands for some part of their life cycle. Shallow wetland pools act as nurseries for the offspring of many species of reptiles, amphibians and fish. And, some of Missouri's most important furbearers—beavers, muskrats, mink and otters—depend on wetlands for food and shelter. When you compare Missouri's wetlands with other ecosystems, only tropical rainforests and coastal salt marshes produce more life per square meter.

Wetlands create and support so much life by turning a tremendous amount of sunlight into usable energy. Each flap of a dragonfly's wings, each millimeter of growth by a cattail leaf, each warble from the throat of a marsh wren—all require energy. Indeed, from birth to death, every organism in a wetland—or any ecosystem for that matter—uses energy to grow, survive and reproduce. To understand how wetlands create and support such a tremendous amount of life, we need to explore the nature of energy, how various organisms use it, and how it is transferred from one organism to another.

Organisms need energy to grow, survive and reproduce.

Energy. Environmentalists contend Americans use too much energy. Politicians argue our country doesn't produce enough energy. Puppies and toddlers are full of energy. A rock band's music might be high energy. Refrigerators and dishwashers are often advertised to be energy efficient. Exercise can increase your energy. Too much work can drain your energy. After reading this chapter, you might claim, "I can't go on. I just don't have the energy." We've all heard of energy. But, what is it and what does it have to do with ecology?

Technically, **energy** is the ability to do work. It's easier, however, to think of energy as something that creates change. For example, it takes energy to change your car from standing still to moving. It takes energy to change your stovetop from cold to hot. It takes energy to change your classroom from dark to bright.



Energy in motion, such as the light waves striking these leaves, is kinetic energy. Energy that is stored, such as the water behind this dam, is potential energy.

Energy comes in many different forms. Heat, light, sound and electricity are all forms of energy. Forms of energy can be sorted into two main categories: kinetic and potential. Energy in motion is called **kinetic energy.** The sound of your teacher talking is kinetic energy because the sound waves produced by his or her voice move through the air to your ears. Because light moves in waves, sunlight is kinetic energy, also. Heat, electricity and the movement of objects are other examples of kinetic energy. Stored energy is called **potential energy**. An easy way to remember the difference between kinetic and potential energy is that potential energy has the potential to move, but is not moving right now. The chemical energy stored in molecules, such as carbohydrates and fats, is potential energy. Because they can potentially move and do work, the water behind a dam and a stretched rubber band also contain potential energy.

Energy cannot be created or destroyed. The total amount of energy in the universe is constant. Energy can, however, change from one form into another. Although you have to recharge your cell phone periodically, the energy it uses doesn't disappear. The cell phone transforms the chemical energy stored in its batteries into electricity, light (on the keypad and display), heat, and electromagnetic waves (which carry your voice from the phone to a cell tower to the person you're calling). The amount of energy your cell phone uses is perfectly balanced by the amount of energy it sends out in the form of light, heat and electromagnetic waves.

What does this have to do with ecology? Everything an organism does requires energy. For example, growing new cells, maintaining body temperature, pumping blood through the body, and escaping from predators all require energy. And, just like your cell phone, organisms get the energy they need by transforming one form of energy into another.

Most of the mass of this gigantic bur oak was built molecule by molecule from water and carbon dioxide in the air. During photosynthesis, the tree used the sun's energy to transform these molecules into glucose. This glucose was used for energy or rearranged and combined with other molecules to form the building blocks that make up the leaves, roots, bark and other parts of the tree.

Most organisms obtain energy through photosynthesis or by eating other organisms.

Just south of Columbia, in the floodplain of the Missouri River, grows a gigantic bur oak. Like all bur oaks, this particular tree began its life as a tiny acorn no bigger than the end of your thumb. Between 300 and 400 years ago—before Missouri became a state, before the Lewis and Clark expedition, before the Declaration of Independence was signed—the acorn fell from its parent, landed in fertile soil, and started to grow. Every year that the bur oak grew, it became a little taller and added a little more wood to its trunk and branches. Today, the tree is one of the largest of its kind, with a height of over 20 meters, a trunk nearly 3 meters in diameter, and a weight of over 20 metric tons. Where did the tree get the raw materials to create so much mass?

Most of the mass of the tree comes from water and carbon dioxide in the atmosphere. The process that begins the transformation of water and carbon dioxide into wood, leaves and other tissues is known as **photosynthesis**. During photosynthesis, plants, algae and some bacteria harness the energy provided by sunlight to transform six molecules of carbon dioxide (CO_2) and six molecules of water (H_2O) into one molecule of the sugar glucose ($C_6H_{12}O_6$) and six molecules of oxygen (O_2). A chemist might write the transformation like this:

$$6CO_2 + 6H_2O \text{ (+ Sunlight)} \rightarrow C_6H_{12}O_6 + 6O_2$$

During this reaction, the energy from sunlight doesn't disappear. Instead, part of the energy is reflected back into the atmosphere, part is transformed into heat, and part is stored in the chemical bonds of the glucose molecule. In essence, photosynthesis changes the kinetic energy of sunlight into the potential energy of glucose.

Glucose is an important molecule. Rearranged and joined together, glucose molecules can be turned into carbohydrates, fats and cellulose. When combined with nitrogen and other elements, glucose can form proteins and nucleic acids, which form the tissues of plants and other photosynthetic organisms. Ecologists refer to this process and the resulting tissues as **primary production**.

Glucose also can be used as an energy source. Although only photosynthetic organisms can convert the energy in sunlight into chemical energy, virtually every organism—from plants to people—can use glucose for energy. During a process called **cellular respiration**, oxygen and glucose react to form carbon dioxide and water. When this happens, the potential energy stored in glucose is released. Organisms use the resulting kinetic energy for growth, survival and reproduction. Plants and other photosynthetic organisms are called **producers** because they take a form of energy that most organisms can't use (sunlight) and *produce* a form of energy that most organisms can use (glucose).

Primary production is affected by temperature, moisture and nutrients.

Studying primary production is important to ecologists because it gives a measure of how much energy is available to the organisms in a community. Ecologists also like to know how fast primary production occurs because this tells them how quickly sunlight can be converted into usable energy.

Primary production is measured in several ways. One commonly used measure is mass per area per unit of time. To figure this, ecologists gather all of the plants (and other primary producers) in a defined area (usually a square meter) that have grown in a set period of time (usually a year). The ecologists dry the plants to remove all the water from their tissues and then determine their mass. This gives an estimate of how much tissue was produced for a given time, in other words, the rate of primary production.

As Figure 6.1 shows, some ecosystems have higher rates of primary production than others. To figure out why, we need to consider what affects the growth of plants and other producers.

Light is important. Without light, photosynthesis cannot occur. For example, the middle of the ocean has low primary production. The deeper you go in the ocean, the less light there is available for photosynthesis. Ecosystems near the poles also have low primary production. At the equator, day and night are equal. As you move away from the equator, the period of day to night shifts based on the season. In the summer, Antarctica has a "night" that last for several months. This long period of darkness limits the amount of primary production that occurs there.

Temperature also is important. Like most chemical reactions, photosynthesis is influenced by temperature. Generally, photosynthesis proceeds slowly at low temperatures and increases (to a point) as temperatures go up. Most producers are adapted to photosynthesize at the average temperature of their ecosystem. Generally, though, photosynthesis occurs best from 16 to 38 degrees C. This explains why colder ecosystems have lower primary production.

Remember that in photosynthesis, the reactants are water and carbon dioxide. Because carbon dioxide is found in adequate supplies in both terrestrial and aquatic ecosystems, it rarely limits primary production. Water, however, can be scarce in some terrestrial ecosystems, for example deserts, tundras and prairies. Without enough water, photosynthesis cannot occur.

Producers, like all organisms, need more than just carbon dioxide, water and sunlight to grow. As stated earlier, glucose combines with other elements to form the building blocks of living cells. Some of the most important elements that glucose combines with include nitrogen and phosphorus. A lack of nitrogen and phosphorus can limit the growth of producers. In terrestrial ecosystems, temperature and water usually limit primary production. In aquatic ecosystems, temperatures are usually stable and water is plentiful. Therefore, in aquatic ecosystems, a lack of nitrogen or phosphorus is often what limits primary production.

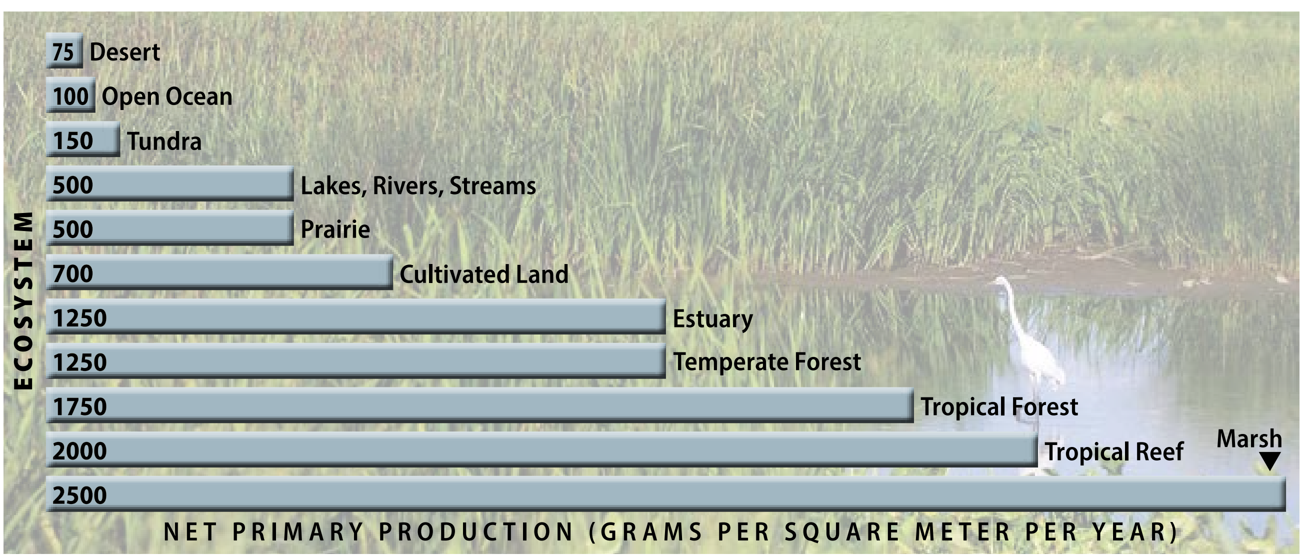


Figure 6.1—Primary Production of Various Ecosystems Measured in g/m^2/year

Knowing what limits primary production can help us hypothesize why wetlands in Missouri contain so much life. By definition, wetlands are wet. So, water is unlikely to be a limiting factor. Missouri's marshes are relatively shallow—often 45 centimeters deep or less—and contain few trees. This allows producers at any depth and any location to receive plenty of sunlight. Because of its latitude, Missouri has longer days in the summer and longer nights in the winter, but this doesn't affect photosynthesis to a large degree. Therefore, we can hypothesize that light isn't a limiting factor, either. Most of Missouri's wetlands are associated with rivers. When the rivers flood, they overflow into wetlands, and deposit nutrients into the wetland soil. This process makes wetlands one of the most nutrient-rich ecosystems on the planet. Therefore, we can hypothesize that nutrients are unlikely to limit wetland primary production. Temperature limits primary production during Missouri's winter, but only for a few months. With these facts, we might hypothesize that wetlands are highly productive because few factors limit primary production. This would explain the enormous amount and variety of plants and other producers found in a wetland, but it doesn't explain all the other organisms that live there. To account for every bullhead, bullfrog and blackbird, we need to examine how energy flows through a wetland community.

Food chains show a specific pathway of energy flow in a community.

Energy flow is the transfer of energy from one organism to another. Because producers take a form of energy that most organisms can't use (sunlight) and convert it into a form of energy that most organisms can use (glucose), energy flow begins with producers. In a wetland, producers include cattails, sedges, bulrushes, smartweeds, arrowheads, algae, and many kinds of phytoplankton (a diverse group of tiny, often unicellular plants, protists and bacteria that live in water).

Organisms that cannot transform sunlight into usable energy must eat or consume other organisms to get energy. These types of organisms are called **consumers**. In a wetland, consumers include muskrats, ducks, fish, water snakes, river otters, mink and zooplankton (tiny aquatic animals and protists). Consumers can be divided into three groups based on what they eat:

- **Herbivores**, such as muskrats, eat plants and other producers.
- **Carnivores**, such as mink, eat other consumers.
- **Omnivores**, such as raccoons and humans, eat both producers and consumers.

Food chains show how energy is transferred from producers to different consumers. For example, Figure 6.2 is a food chain that shows how energy is transferred when algae, which are producers, are eaten by a pond snail, which is then eaten by a crayfish, and so on all the way up the food chain to the mink. Here are some other food chains that illustrate how energy is transferred when one organism eats another:

Algae→pond snail→bullfrog→northern water snake→great blue heron
Arrowhead→blue-winged teal→northern harrier
Arrowhead→muskrat→mink

Each food chain shows the specific pathway that energy from the sun takes as it is transformed by a producer and then incorporated into the tissues of different consumers. To draw all the pathways the sun's energy might take in a community, we would need to draw a food web.

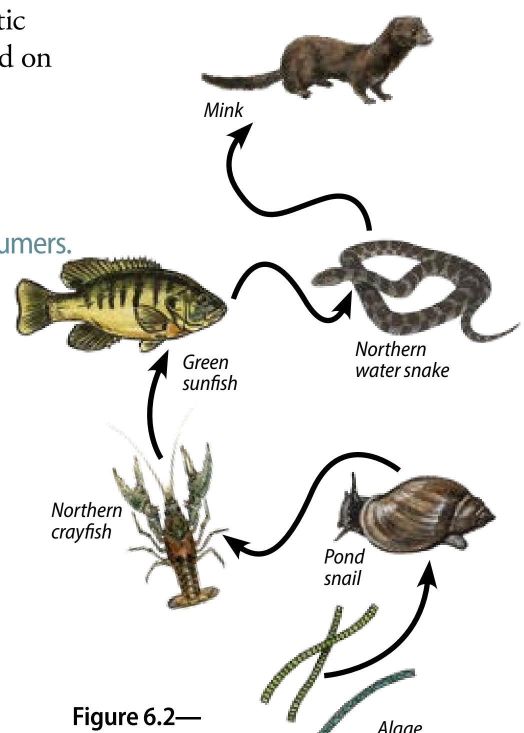


Figure 6.2—Food chains show how energy from the sun is transferred from a producer to various consumers. In this chain, energy flows from algae through several mid-level consumers to a mink.

Stocking Ponds

What does soil fertility have to do with stocking fish in a pond? Quite a bit, as it turns out. Fisheries biologists typically recommend stocking a combination of largemouth bass, bluegill and channel catfish fingerlings into a new pond. In locations where soil fertility is high, biologists prescribe 100 bass, 500 bluegill and 100 catfish for each half hectare of surface water in the pond. In areas with poor soil fertility, biologists recommend a ratio of 50 bass, 250 bluegill and 50 catfish. Why is there a difference in stocking rates?

It has to do with primary production. A pond's most important producers are microscopic plants called phytoplankton. Millions of these tiny plants give some pond water a greenish tint. Phytoplankton, like all producers, need more than carbon dioxide, water and sunlight to grow. They also require nutrients, such as nitrogen and phosphorus. These nutrients wash from the soil and dissolve in pond water. In areas with high soil fertility there are more nutrients available, and primary production by phytoplankton is higher.

Phytoplankton form the first link in a pond food chain. Phytoplankton are eaten by tiny animals called zooplankton. Aquatic insects, such as dragonfly, damselfly and mayfly larvae, feed on both zooplankton and phytoplankton. These insects are, in turn, eaten by fish.

Young bluegill survive on plankton and aquatic insects. When they get larger, bluegill add snails, small crayfish and small fish to their diet. In ponds, catfish do not play a significant role as predators. Instead, they feed on injured or dead fish and aquatic insects, crayfish and algae. At the top of the pond's food chain, bass eat bluegill, frogs, crayfish and other small animals. For each kilogram of bass produced in a pond, 3,676 kilograms of phytoplankton, zooplankton, insects and bluegill must be available in the pond's food chain.

Understanding how energy flows through a pond helps fisheries biologists fix common pond problems. Many ponds contain an overabundance of 20- to 30-centimeter long bass. Biologists call this a stockpiled bass population. The bass get just enough food to stay alive, but not enough to grow very large. They usually have long, skinny bodies, hollow bellies and disproportionately large heads. Many pond owners assume these are young fish; however, they may be several years old. A stockpiled bass population can result from a number of things. The most common involves a pond where bass harvest is limited and bass reproduction is very good. Under these circumstances, bluegill, the primary prey of bass in ponds, cannot produce enough young to adequately feed the large numbers of bass. To solve the problem, biologists usually recommend increasing bass harvest by instituting a **slot length limit**. A slot limit is a special harvest tool in which fish under and over a certain length range can be harvested, but those that fall within a certain length range—the slot—have to be returned to the water. For stockpiled bass, anglers are encouraged to harvest fish less than 30 centimeters long, but to return to the water all fish between 30 and 40 centimeters. Bass longer than 40 centimeters may be harvested or released depending upon the angler's preference. Removing a large number of the smaller bass makes more food available to the remaining fish. In time, the remaining fish will grow larger, and the food chain will balance out.

A fisheries biologist stocks a lake with channel catfish.

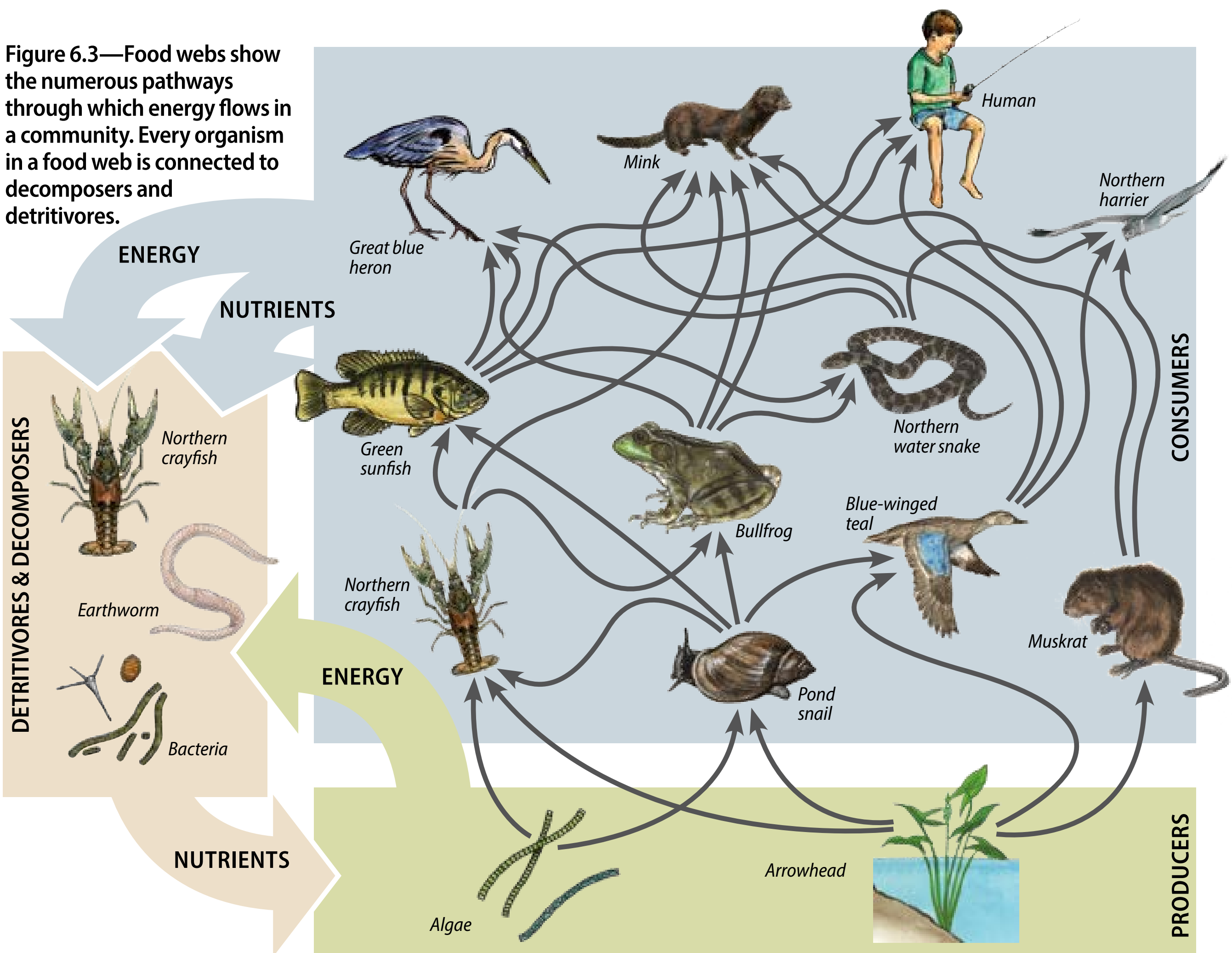
Food webs are complex illustrations of interconnected food chains.

Figure 6.3 takes the four food chains we talked about earlier and connects all the possible pathways energy could take as it is transferred from one organism to another. Ecologists call this kind of illustration a **food web**. Food webs show how food chains are interconnected. Ecologists use food webs to summarize energy flow in a community.

The food web shown below illustrates just a few of the millions of pathways through which energy flows in a wetland. Biologists have estimated that nearly half of Missouri's 3,200 plant species are associated with wetlands. Connecting the food chains associated with more than 1,500 producers and the thousands of consumers that eat them would make an extremely complicated food web!

Food webs become even more complex when we add in detritivores and decomposers. **Detritivores** are organisms that get their energy by feeding on dead organisms. By feeding on dead organisms and then excreting wastes, detritivores break down dead organisms into smaller pieces. Common detritivores in a wetland include crayfish, worms and many aquatic insects. **Decomposers** also feed on dead organisms, but they break the organisms down even further. Decomposers take the large molecules found in the tissues of an organism (such as carbohydrates, lipids and proteins) and break them down into simpler molecules (such as carbon dioxide, nitrogen and phosphorus). In doing so, decomposers create molecules that can be reused by producers during photosynthesis. Bacteria and fungi are often decomposers. Because every organism eventually dies, every organism in a food web can also be connected with one or more decomposers or detritivores.

Figure 6.3—Food webs show the numerous pathways through which energy flows in a community. Every organism in a food web is connected to decomposers and detritivores.



More species live in marshes that have muskrats than marshes that don't. By eating cattails, muskrats make room for other plants and animals. Since this increases the number of organisms in a marsh food web, muskrats are a keystone species.

By studying food webs, ecologists can make predictions on how the removal of one organism will impact other organisms in the community. For example, if all the algae suddenly disappeared from the wetland, not only would snails and crayfish be affected, but also the organisms that eat snails and crayfish, plus the organisms that eat those organisms, and every other food chain in the food web.

Some species affect a food web more than others.

In the same way that dandelions can quickly cover a lawn, cattails, if left unchecked, can quickly cover a shallow marsh. The consequences of this can be disastrous. Cattails can outcompete many other wetland plants for sunlight, space and nutrients. When these less-dominant wetland plants disappear, the organisms that use them for food or shelter disappear as well. Of course, the organisms that use wetland plants are themselves food for organisms higher on the food chain. In this way, a bumper crop of cattails can disrupt an entire wetland food web.

Enter the muskrat. Like a little rodent lawnmower, muskrats cut down cattails, bulrushes and other aquatic plants for food. They also use the plants to construct mound-shaped dens and feeding platforms throughout the marsh. Keeping a muskrat fed and housed requires a lot of plants. By removing many cattails from a wetland, muskrats allow less-dominant plants to gain a foothold. This creates a greater diversity of plants, which leads to a greater diversity of herbivores. A greater diversity of herbivores leads to a greater diversity of carnivores. By removing many of the cattails, muskrats also create areas of open water that can be used by species of waterfowl, fish and amphibians. So, just by reducing the dominance of cattails, muskrats have a staggering effect on the number of organisms in a wetland food web. Species like muskrats that affect a food web more so than other species are called **keystone species**.

It's important to avoid confusing keystone species with dominant species. A dominant species—like cattails or phytoplankton—may be one of the most abundant organisms in a community. Because of its abundance, dominant species usually have a strong influence over how energy flows through the community. In contrast, keystone species are usually one of the least abundant organisms in the community. However, despite their low numbers, they have a disproportionate effect on the way energy flows through the community.

Using a Keystone Lizard to Regrow Glades

Glades harbor some of Missouri's most interesting organisms. Nowhere else in the state can you find roadrunners, tarantulas, prickly pear cacti and collared lizards. Unfortunately, many glades in Missouri aren't very healthy. Overgrazing by livestock has destroyed many glades, and years of fire suppression has degraded others. Without fire to keep trees in check, dense thickets of red cedars and post oaks invade glades, eventually shading out many of the sun-loving plants and animals that live there.

The Conservation Department, other government agencies and some private landowners are working to restore degraded glades in Missouri. Cedar-choked glades can be transformed back to open areas with an abundance of native plants and animals. All it takes is a little hard work.

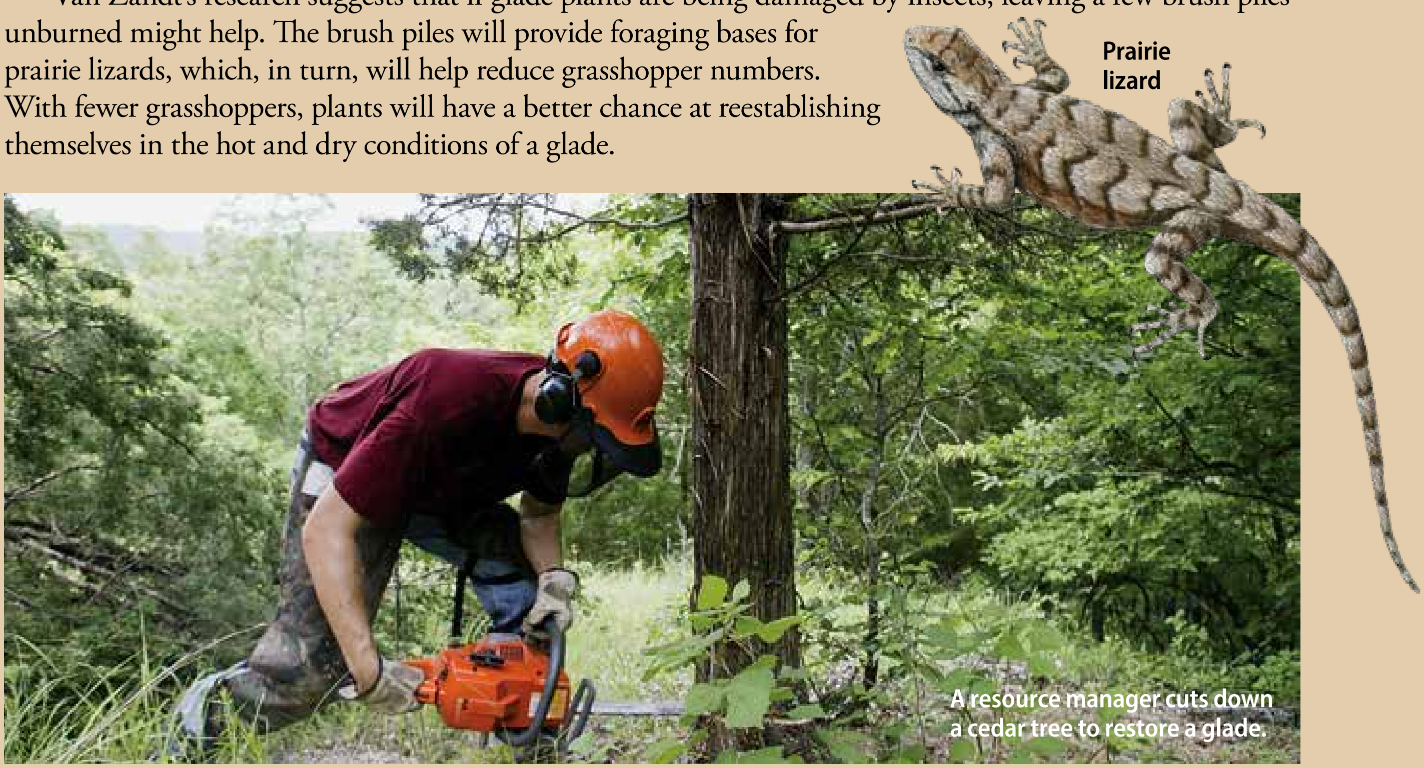
First the cedars and oaks have to be cut down. In the summer, this is sweaty, back-breaking work; in the winter, it's just back-breaking. Although some managers haul the cut trees to lumber mills, most stack them into brush piles. When the glade is burned, the brush piles burn up, too. This leaves a nice bare area for glade plants to regrow.

Glade plants have a tough time reestablishing if there are too many grasshoppers and other insects around. Grasshoppers can strip 10 to 80 percent of the foliage from glade plants in a single growing season. Although this doesn't usually kill the plants, it does lower the plants' reproduction, making it difficult for plant populations to increase.

Prairie lizards are voracious predators of grasshoppers. Prairie lizards, however, are homebodies and rarely venture far from shelter. They use boulders and brush piles as refuges from predators, places from which to ambush prey, and for shade to regulate their body temperature.

Peter Van Zandt and other researchers at Washington University in St. Louis found that glades might benefit if brush piles were left unburned. Van Zandt measured how far from shelter prairie lizards typically foraged. He also measured grasshopper densities and plant damage at various distances from brush piles. He found that over 85 percent of all lizards were observed within 1 meter of some kind of cover. As one might expect, grasshopper densities and plant damage increased at greater distances from cover.

Van Zandt's research suggests that if glade plants are being damaged by insects, leaving a few brush piles unburned might help. The brush piles will provide foraging bases for prairie lizards, which, in turn, will help reduce grasshopper numbers. With fewer grasshoppers, plants will have a better chance at reestablishing themselves in the hot and dry conditions of a glade.



Prairie lizard

A resource manager cuts down a cedar tree to restore a glade.

In many ecosystems, the top predator in a food chain often acts as a keystone species. When white-tailed deer populations get too large, deer can strip the vegetation from an area. This is disastrous not only for the plants, but also for other organisms higher in the food chain. By harvesting deer, human hunters play the role of keystone predator once occupied by mountain lions and wolves. In doing so, hunters keep deer populations low, which keeps plant populations healthy. In turn, healthy plant populations support a much more complex food web.

Ecologists and resource managers find it important to identify the keystone species in an ecosystem. While each organism plays a role in the flow of energy and the functioning of an ecosystem, the loss of keystone species has a greater consequence than the loss of other, less influential species.

Energy pyramids simplify food webs by sorting organisms into trophic levels.

To simplify food webs, ecologists sort organisms into trophic levels. A **trophic level** is the position an organism occupies in a food chain. Knowing an organism's position in a food chain helps an ecologist predict what it might eat and what might eat it.

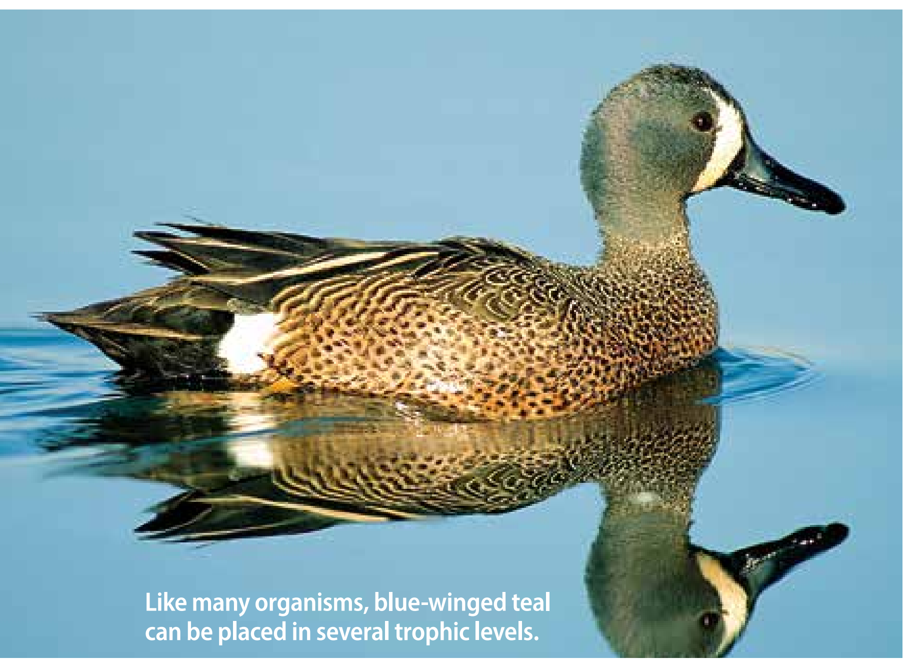
You're already familiar with one trophic level: producers. This trophic level contains all of the plants (such as cattails), phytoplankton, and other organisms in a particular community that use photosynthesis to convert sunlight into chemical energy. Because producers convert the sun's energy into other usable forms of energy, they make up the first trophic level.

Organisms that eat primary producers are grouped into a second trophic level: primary consumers. In a wetland, all of the herbivores, such as pond snails, fathead minnows and muskrats, would be grouped together as primary consumers.

The third trophic level is made up of secondary consumers that eat primary consumers. These organisms are primarily omnivores and carnivores, such as green sunfish, northern water snakes and bullfrogs.

The fourth trophic level is made up of tertiary consumers, such as mink and great blue herons, that eat secondary consumers. The fifth trophic level is made up of quaternary consumers, such as humans and other top level carnivores, that eat tertiary consumers. In this system each trophic level feeds on the one immediately below it.

Not every organism falls neatly into a single trophic level. Blue-winged teal migrate between breeding habitat in Canada and wintering habitat in the southern United States and Central America. On the way, they stop in Missouri's wetlands to fuel up for their long flights. In the fall, blue-winged teal eat mainly seeds, which are high in carbohydrates and provide quick energy for a fast flight south. In the spring, however, blue-winged teal shift their diet to consume more aquatic invertebrates, which provide extra protein they need for reproduction. In the fall, blue-winged teal are mostly primary consumers, while in the spring they are mostly secondary consumers.


Like many organisms, blue-winged teal can be placed in several trophic levels.

A mound of all the cattails, algae and other primary producers would tower over all the snails, minnows, blue-winged teal and other primary consumers. Likewise, a mound of primary consumers would make all the green sunfish,

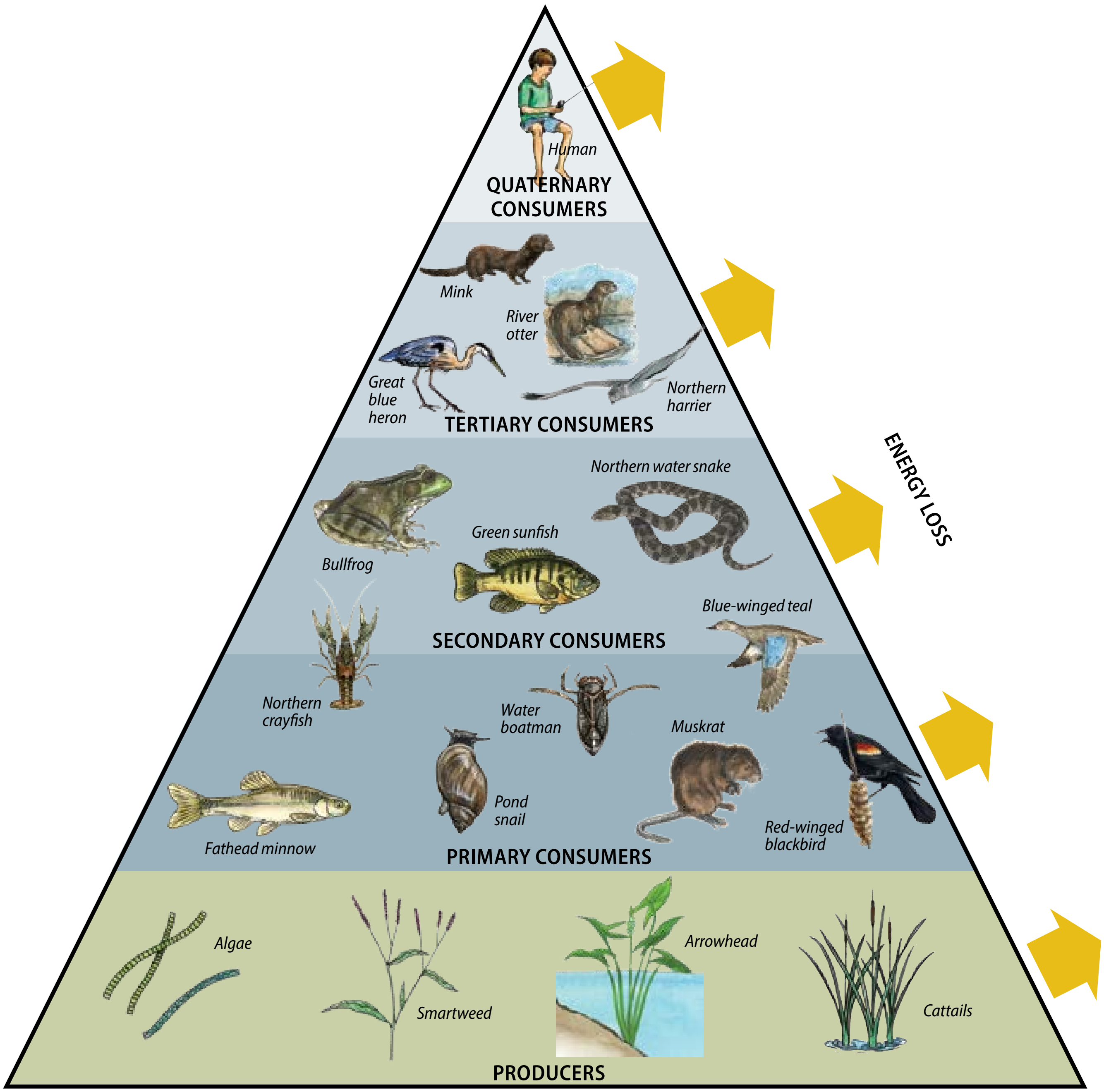


Figure 6.4—An energy pyramid's shape shows that consumers at higher trophic levels have less energy to support them than consumers at lower trophic levels.

northern water snakes and other secondary consumers look tiny in comparison. Moving from a lower trophic level to a higher trophic level, the combined mass of the organisms decreases. Because the mass of an organism is related to the amount of energy contained in the organism's tissues, ecologists use the mass of all the organisms in a trophic level to estimate how much energy is contained in that trophic level. When ecologists stack these energy estimates on top of each other with primary producers forming the base and going up through all of the consumers, the resulting graph forms a pyramid shape like Figure 6.4. **Energy pyramids** show how much energy is available at each trophic level.

In an energy pyramid, less energy is contained in each higher trophic level. We know that energy cannot be created or destroyed, so why does this happen, and where does the lost energy go? To answer these questions, we have to understand how organisms use the energy they consume.

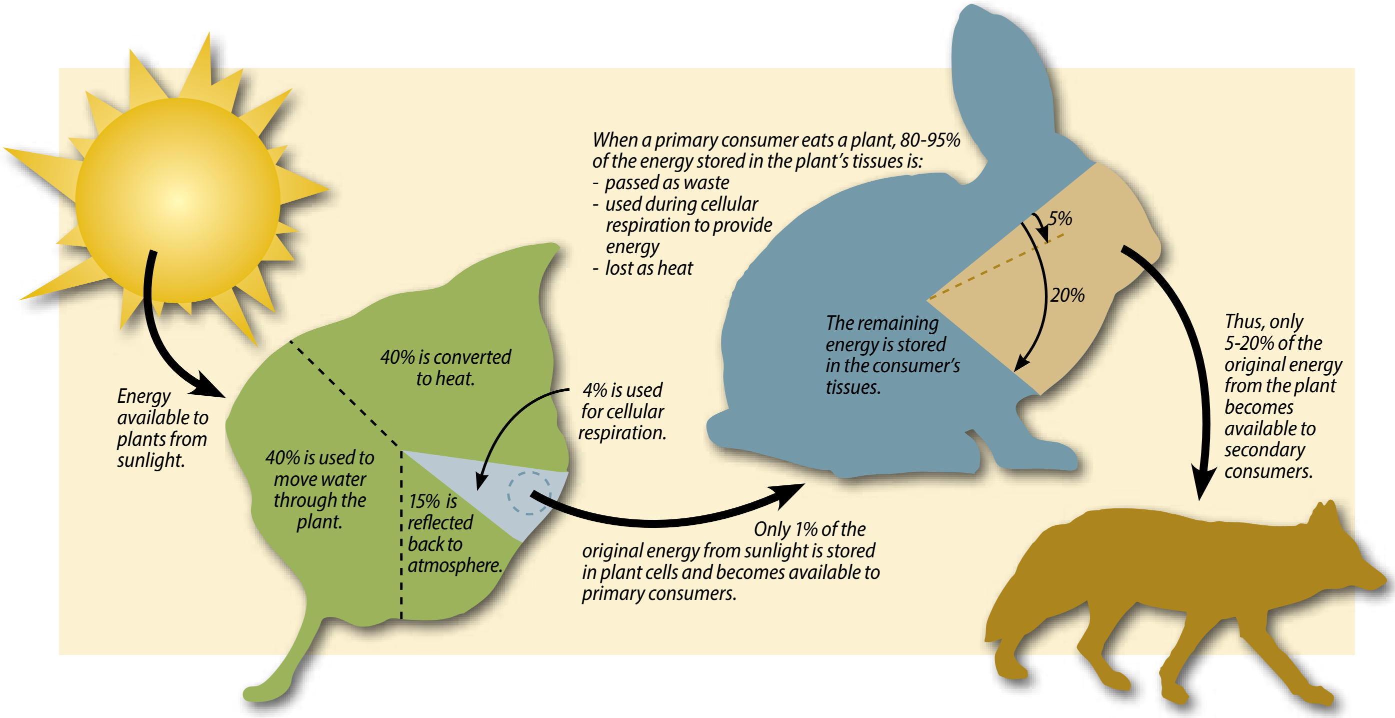


Figure 6.5—In general, only 5 to 20 percent of the energy in a trophic level passes to the one that follows.

Only about 5 to 20 percent of energy passes from one trophic level to the next.

Let's begin with plants. In general, of the energy available in sunlight, about 15 percent is reflected back into the atmosphere, 40 percent is converted to heat, and 40 percent is used to pull water from the ground through the roots to the leaves *(Figure 6.5)*. This leaves only about 5 percent for photosynthesis. Plants use a portion of the energy converted by photosynthesis during cellular respiration, which fuels the processes that keep plants alive. The rest of the energy—about 1 percent—is stored in cells as the plant grows or produces offspring. This energy—about 1 percent of the total energy from sunlight—is available to primary consumers.

Primary consumers eat plants to gain energy, but not all of the plant is easily digested. Cellulose, lignin and certain other tissues often pass through the primary consumer's digestive tract and are excreted as waste. In this way, the energy contained in these tissues is lost to the primary consumer. Other organisms, such as detritivores and decomposers, can use the energy in this waste. Of the plant's tissues digested by the primary consumer, a large portion is used in cellular respiration to provide energy for processes, such as breathing, pumping blood and running from predators, that keep the primary consumer alive. These processes produce heat, which escapes into the air or water surrounding the organism. In this way, another large portion of the energy contained in the plant's tissues is used (in the case of cellular respiration) or transferred to the environment (in the case of heat). The rest of the energy in the plant's tissues is used to form new cells, which increase the size of the primary consumer or are used to produce offspring. This small fraction—between 5 to 20 percent of the original energy in the plant's tissues—becomes available to secondary consumers at the next trophic level.

The same thing continues at each higher trophic level. Secondary consumers cannot digest all of the bones, hair and teeth of the animals they consume, so some of this energy becomes fuel for decomposers instead of fuel for the consumer. Most of what is digested is used to keep the secondary consumer alive. Only a small fraction of the total energy gets stored in the secondary consumer's cells. Therefore, at each

In nearly every ecosystem, there always are more plants than herbivores, more herbivores than carnivores, and always just a few top-level predators such as this mink.

trophic level, 80 to 95 percent of the energy contained in the trophic level immediately below it is lost due to three things:

- The inability to digest certain tissues from organisms in a lower trophic level
- The use of energy to keep the organism alive
- The loss of energy as heat transferred to the environment

In general, only about 5 to 20 percent of the energy in a trophic level passes to the one immediately above it. This explains the triangular shape of energy pyramids. It also explains why most food chains have five or fewer links. Each time we move up a trophic level, there is less energy available. At some point, the energy runs out, and there isn't enough to support higher-level consumers. This is why in nearly every ecosystem there are always more plants than herbivores, more herbivores than carnivores, and always just a few top-level predators such as mink, herons and harriers. ▲

Atoms are recycled over and over again by living things. An atom forming the whisker of this deer mouse might have formed the toenail of a *Tyrannosaurus rex* millions of years ago.

BIG IDEAS:

- All matter is composed of atoms.
- Physical and chemical processes move atoms through ecosystems.
- Atoms cannot be created or destroyed.
- Atoms follow specific pathways through ecosystems.
- Human populations affect element cycles.

THE Cycling OF Elements THROUGH ECOSYSTEMS

For a billion years, the atom bided time locked in a limestone shelf deep underground. Time means nothing to an atom that has existed forever and will always exist. Continents surfed slowly above, their grinding and colliding liquifying the limestone and moving the atom closer and closer to freedom.

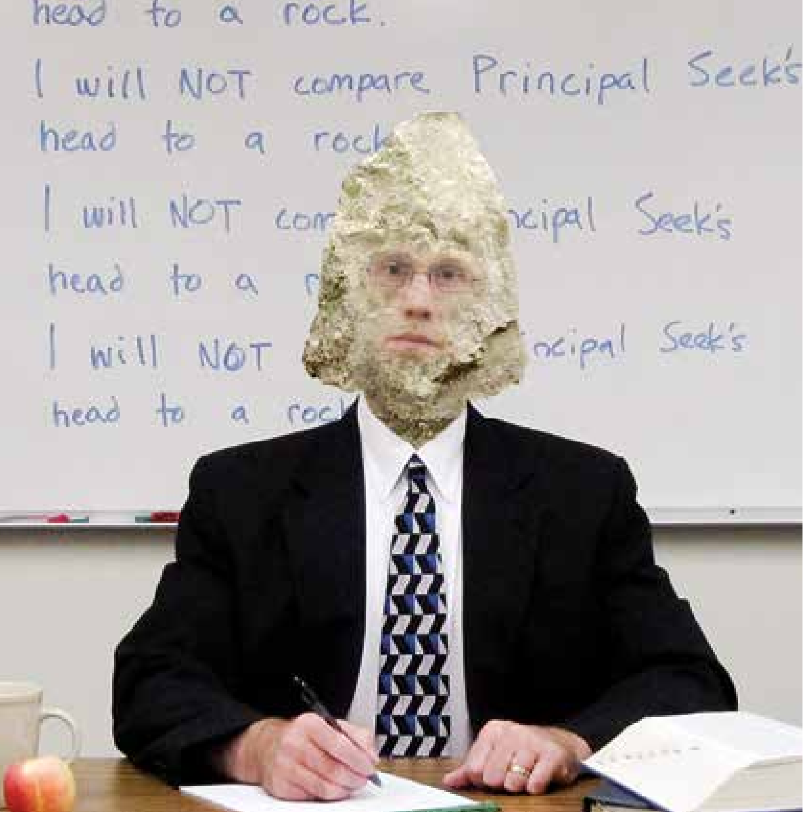
A volcano finally released the atom from its imprisonment. With a belch of superheated gas, the atom was discharged and airborne, as carefree as the wind upon which it now rode. The atom spent a decade in the atmosphere, sailing above supercontinents and immense oceans. One still morning, it drifted too close to the pore of a tree fern, and in the blink of an eye the atom was sucked into the helter-skelter world of living things.

The atom helped build a leaf, which was promptly nipped off by a grazing brachiosaurus, which fell prey to the slashing jaws of an allosaurus, all in a single year. From its berth in the allosaur's bones, the atom did its part to keep the beast lumbering across the swampy land, but every living thing eventually dies, and the allosaur, despite its ferocity, was no exception.

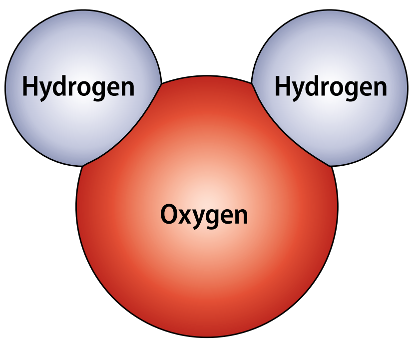
Millennia passed, then epochs. The atom embarked on countless journeys in the bodies of creatures great and small—the hamstring of a Neandertal one year, the tooth of a saber-toothed cat the next. For a brief spell it returned to the atmosphere, but was quickly pulled earthbound to form an acorn, which fed a deer mouse, which fed a hawk. When the hawk died the following summer, the atom turned up in a blade of prairie grass, which fed a deer mouse, with neither atom nor hawk realizing the irony.

In time, the atom helped build a kernel of corn, which fed a beef cow, which became a cheeseburger that was eaten by an ecology student last night for supper. Presently, the atom is helping provide energy to the student, enabling her to think about what she is reading in class. The student, either from boredom or enlightenment, sighs. And, with that single breath, the atom is exhaled, free to sail the atmosphere yet again.

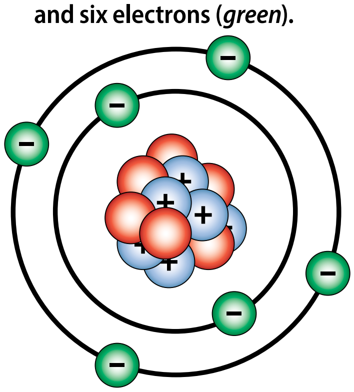
In the last chapter, we learned how energy from the sun makes a one-way trip through an ecosystem. Atoms, on the other hand, get recycled through ecosystems over and over again in a process ecologists call **element cycling**. In this chapter, we will learn about several atoms that are particularly important to life and explore how these atoms are recycled through ecosystems.



Your principal's head and a chunk of limestone are made of many of the same kinds of atoms.



A carbon atom (*below*) is made up of six protons (*blue*), six neutrons (*red*) and six electrons (*green*).



A water molecule (*above*) is a compound made of two hydrogen atoms bonded to one oxygen atom.

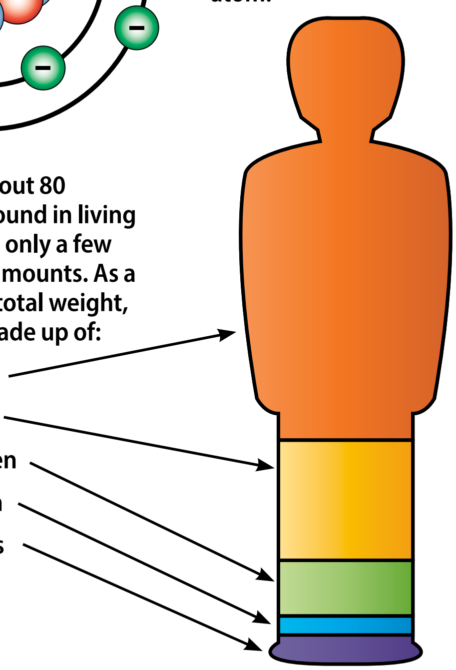


Figure 7.1—About 80 elements are found in living organisms, but only a few occur in large amounts. As a percentage of total weight, your body is made up of:

65% – Oxygen
18% – Carbon
10% – Hydrogen
3% – Nitrogen
4% – *All others*

All matter is composed of atoms.

How is your principal's head like a rock? Just like a rock, your principal's head is composed of atoms. In fact, if the rock were a chunk of limestone, your principal's head and the rock would be composed of many of the same kinds of atoms, such as carbon, oxygen and calcium. Two key differences exist, however, between a chunk of limestone and your principal's head. For one, your principal's head is composed of living cells, while limestone is composed of nonliving minerals. For another, the majority of atoms in limestone are arranged to form a single compound called calcium carbonate. The atoms in your principal's head, however, are arranged to form many different kinds of molecules, each playing an important role in keeping your principal alive and kicking. The point of this is that all matter—whether living or nonliving—is composed of atoms.

Atoms are classified as **chemical elements** based on the number of protons found in the atom's nucleus. For example, an atom of the element carbon has six protons in its nucleus. Elements can combine to form molecules and compounds. A **molecule** is formed when two or more atoms combine. The oxygen we breathe exists as a molecule of two oxygen atoms joined together by a chemical bond (O_2). A **compound** is a molecule that contains at least two *different* elements. Water is a compound made of two hydrogen atoms bonded to one oxygen atom (H_2O). All compounds are molecules, but not all molecules are compounds.

About 80 different elements are found in the cells and tissues of living organisms. Some elements are vital to life, but occur in small quantities in most organisms. Without iron, which is found in hemoglobin in red blood cells, your blood could not transport oxygen throughout your body. Iron, however, makes up only 0.006 percent of your body weight. Like iron, the majority of elements occur in tiny amounts in most organisms.

A few elements occur in large amounts in living organisms. About 65 percent of your weight comes from the oxygen atoms in your body. Carbon makes up about 18 percent of your weight, and hydrogen and nitrogen make up 10

and 3 percent respectively *(Figure 7.1)*. In fact, most of the mass of nearly any organism is made up of just five elements: oxygen, carbon, hydrogen, nitrogen and phosphorus. When combined in various ways, these elements form every carbohydrate, lipid, protein or nucleic acid. Carbohydrates, lipids, proteins and nucleic acids, which biologists call **biomolecules**, are the basic building blocks of cells, which, in turn, compose tissues, organs and organisms. Because of the relative importance of oxygen, carbon, hydrogen, nitrogen and phosphorus to living things, ecologists often study the availability and movement of these elements in ecosystems.

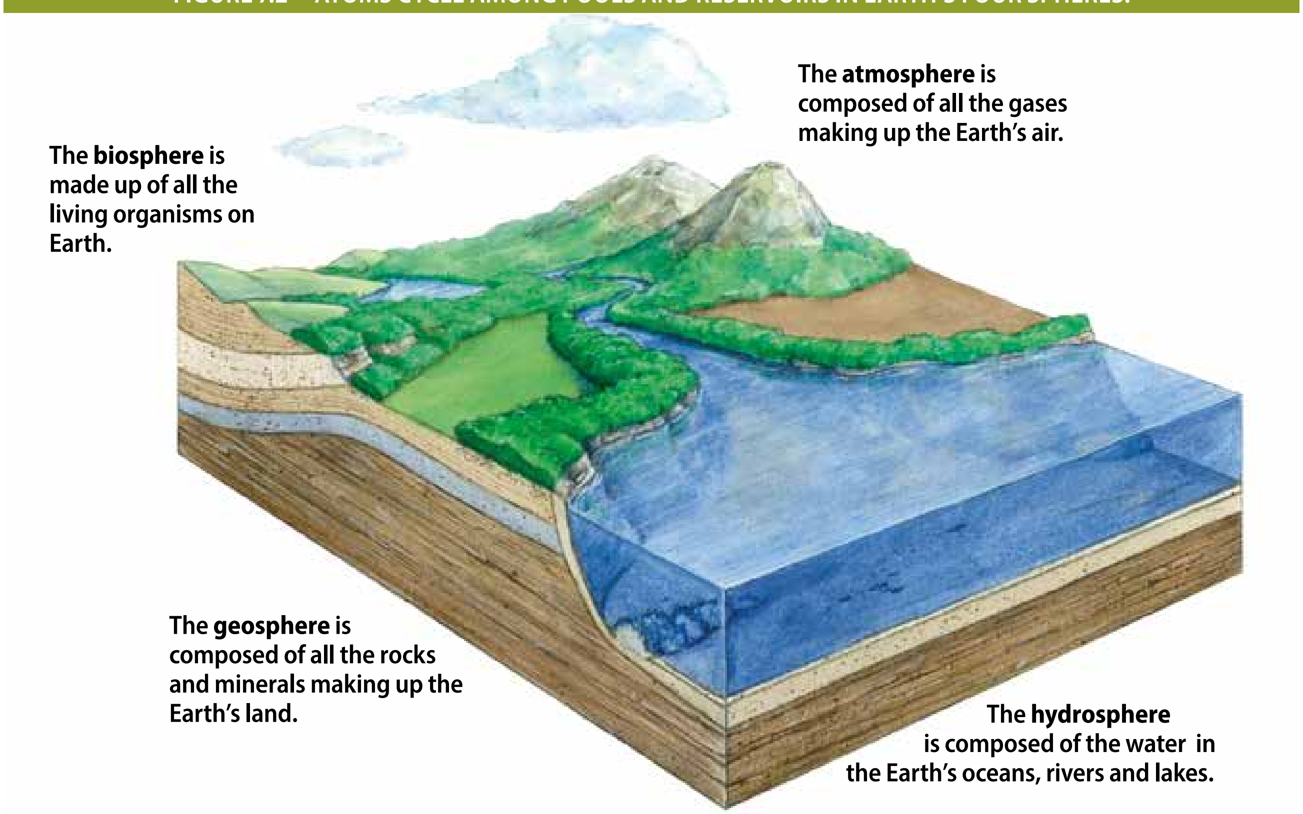
Physical and chemical processes move atoms through ecosystems.

Organisms acquire the atoms they need from the ecosystem in which they live. Some organisms, such as humans and most other animals, obtain atoms by eating other organisms, drinking water and breathing air. Other organisms, such as plants and fungi, get atoms by absorbing them from their surroundings.

Organisms find atoms in various places within an ecosystem. Places where atoms collect for a short length of time—a few hours to a few years—are called **pools**. Places where atoms reside for longer periods of time—decades to millions of years—are called **reservoirs**. Ecologists generally lump all the pools and reservoirs where atoms can end up into four general "spheres" *(Figure 7.2)*. The **biosphere** is made up of all the living organisms on Earth. The **geosphere** is composed of all the rocks and minerals making up the Earth's land. The **hydrosphere** is composed of the water in the Earth's oceans, rivers and lakes. The **atmosphere** is composed of all the gases making up the Earth's air.

Physical and chemical processes move atoms from one sphere to another. When water evaporates, hydrogen and oxygen atoms move from the hydrosphere to the atmosphere. This is a physical process. During photosynthesis and other biological processes, hydrogen and oxygen atoms in water are chemically rearranged to form various molecules that make up the tissues of plants and other organisms. Here, chemical processes move hydrogen and oxygen from the hydrosphere, geosphere and atmosphere into living things, which make up the biosphere.

FIGURE 7.2—ATOMS CYCLE AMONG POOLS AND RESERVOIRS IN EARTH'S FOUR SPHERES.



The atoms that were here when Earth first formed are the same atoms organisms use today. An atom in the eyelash of a mastodon that lived thousands of years ago might be the same atom helping to form your fingernail today.

Atoms cannot be created or destroyed.

Gravity keeps Earth's matter—even gases like oxygen and carbon dioxide—from floating off into space. This is good, because atoms, like every other part of the universe, are subject to certain physical laws. One of these, the **law of conservation of matter**, states that matter cannot be created or destroyed. This means that organisms cannot create new atoms whenever they need them. It also means that the atoms that were here when the Earth first formed are the same atoms organisms use today. Atoms are simply recycled and reused over and over again. In this way, a carbon atom in your toenail might have formed the eyelash of a mastodon or the tooth of a *Tyrannosaurus rex*.

Chemical processes can combine and rearrange atoms from one molecule into another. In each chemical reaction, however, the products of the reaction always balance the reactants. Look closely at the chemical equation for photosynthesis:

$$6CO_2 + 6H_2O \text{ (+ sunlight)} \rightarrow C_6H_{12}O_6 + 6O_2$$

On the left side of the equation there are six carbon atoms, 18 oxygen atoms and 12 hydrogen atoms. On the right side there are the same amounts of each atom. Even though carbon dioxide and water get transformed into sugar and oxygen, the amounts of each kind of atom remain unchanged. In the next section, we'll explore how several atoms important to life are recycled, reused and rearranged as they move through ecosystems.

Atoms follow specific pathways through ecosystems.

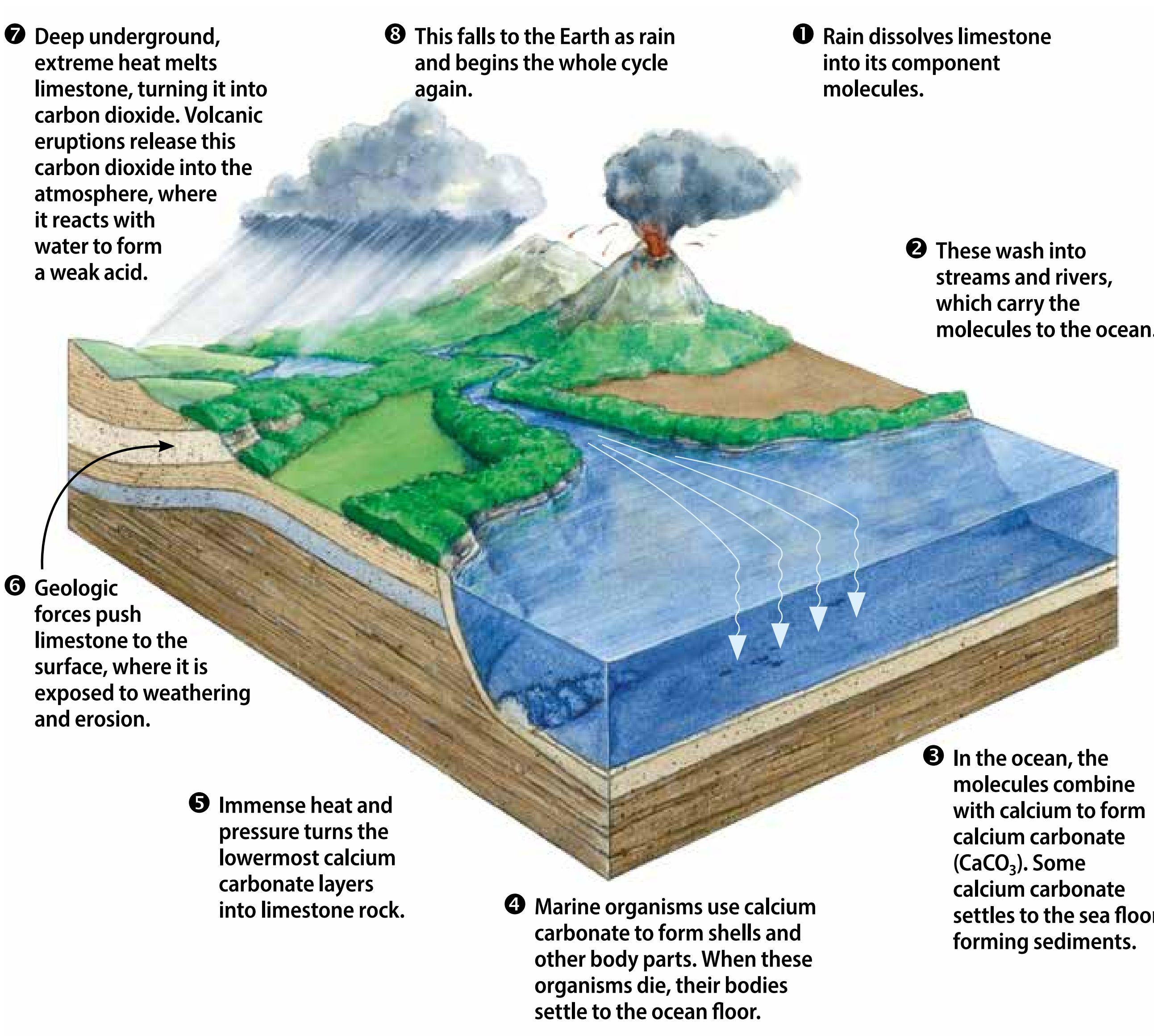
THE CARBON CYCLE

Carbon, the fourth most abundant element in the universe, is the frame upon which every molecule (except water) used by living things is built. The vast majority—about 99 percent—of Earth's carbon is locked in the geosphere, mostly in sedimentary rocks, such as limestone, but also—though to a much smaller extent—in deposits of coal, oil and natural gas. Oceans and lakes contain the next largest pool of carbon, in the form of carbon dioxide (CO_2) dissolved in water. Living organisms and the remains of dead organisms in the soil make up the third largest pool of carbon. Compared to the other pools and reservoirs, a relatively tiny amount of carbon exists in the atmosphere as carbon dioxide, and, to a lesser degree, methane (CH_4).

Carbon moves among its various pools and reservoirs in two basic cycles—the **geological carbon cycle** and the **biological carbon cycle**. It takes millions of years for carbon to make the round trip through the geological cycle. The biological cycle takes a few hours to a few thousand years.

In the geological cycle, carbon moves among the geosphere, atmosphere and hydrosphere. Rain, which is a weak acid, can dissolve exposed limestone into its component molecules. These wash into streams and rivers, which carry the molecules to the ocean. In the ocean, the molecules combine with calcium to form calcium carbonate ($CaCO_3$). Some calcium carbonate settles to the sea floor forming sediments. Other calcium carbonate molecules are used by marine organisms, such as mollusks and corals, to form shells and other body parts. When these organisms die, their bodies settle to the sea floor as well. As more and more calcium carbonate sediments are deposited, immense pressure turns the lowermost layers into limestone rock. When Earth's geologic plates shift, some of this limestone is pushed upward, where it becomes exposed to weathering and erosion. Other limestone is pushed deeper underground where extreme heat melts the limestone, turning it into carbon dioxide. Volcanic eruptions, thermal vents and geysers release this carbon dioxide into the atmosphere, where it reacts with water to form a weak acid. This falls to the Earth as rain and begins the whole cycle again.

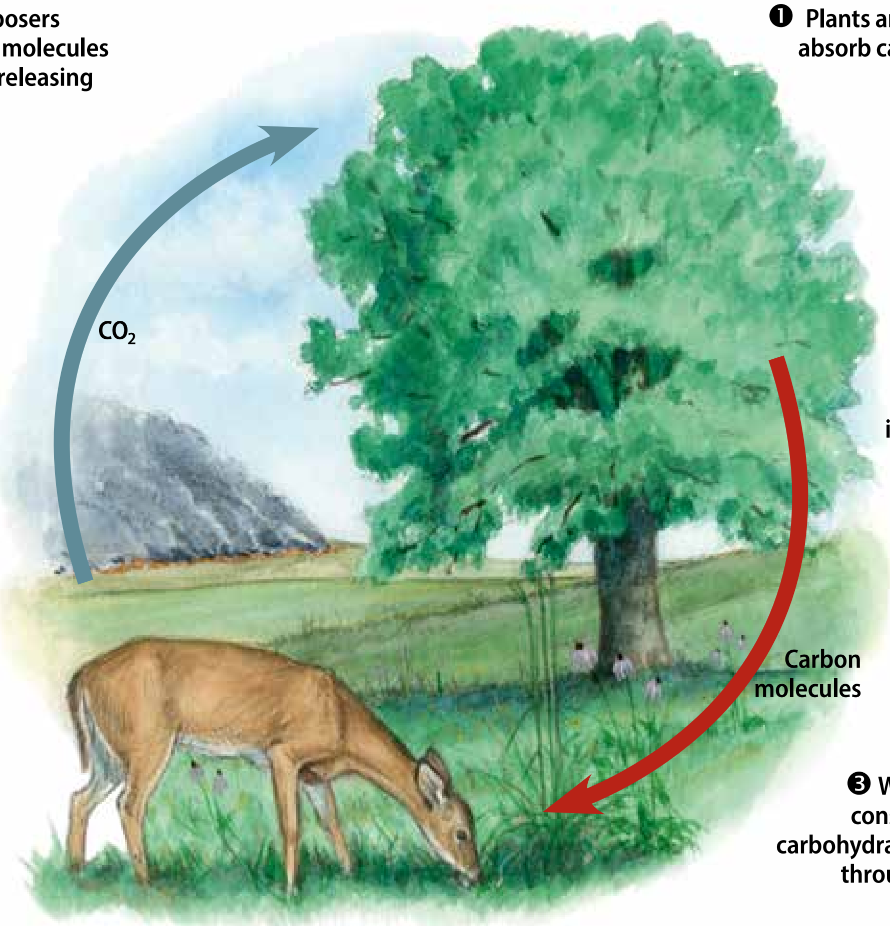
FIGURE 7.3—THE GEOLOGICAL CARBON CYCLE



The biological carbon cycle is closely tied to the flow of energy through ecosystems *(Figure 7.4)*. Plants and other producers absorb carbon dioxide from the air or water, and convert it through photosynthesis into carbohydrates. Producers store a portion of these carbohydrates in their tissues. When one organism consumes another, the carbohydrates are transferred through food chains. Most carbon leaves the biosphere through cellular respiration, in which organisms use carbohydrates (and other molecules derived from them) for energy. The chemical reactions that take place during respiration produce carbon dioxide (or methane in certain cases), which is released into the surrounding air or water. Carbon can leave the biosphere in other ways. Fires consume organisms, releasing carbon compounds into the atmosphere. Bacteria, fungi and other decomposers break down carbon molecules in dead organisms, releasing carbon dioxide and methane into the atmosphere and hydrosphere.

When photosynthesis exceeds cellular respiration and decomposition, organic matter builds up in the geosphere. This happened about 300 million years ago, during the Carboniferous period, when billions of tons of organic matter was deposited and covered by sediments. Over millions of years, these deposits formed fossil fuels, such as coal, oil and natural gas. Burning fossil fuels releases the carbon once contained in prehistoric organisms back into the atmosphere.

FIGURE 7.4—THE BIOLOGICAL CARBON CYCLE



❶ Plants and other producers absorb carbon dioxide from the air or water.

❷ They convert it through photosynthesis into carbohydrates. Producers store a portion of these carbohydrates in their tissues.

❸ When one organism consumes another, the carbohydrates are transferred through the food chain.

❹ Organisms convert carbohydrates into energy during cellular respiration.

❺ Cellular respiration produces carbon dioxide (or methane in certain cases), which is released into the surrounding air or water.

❻ Fire and decomposers break down carbon molecules in dead organisms, releasing carbon dioxide and methane into the atmosphere and hydrosphere.

THE PHOSPHORUS CYCLE

Although phosphorus makes up less than 1 percent of most organisms, life could not exist without it. Phosphorus helps form DNA, RNA and the energy molecule ATP. It is a structural component of cell membranes, bones and teeth. Compared to other element cycles, the phosphorus cycle isn't complicated, but it is slow *(Figure 7.5)*. It normally takes millions of years for phosphorus to cycle among the geosphere, biosphere and hydrosphere.

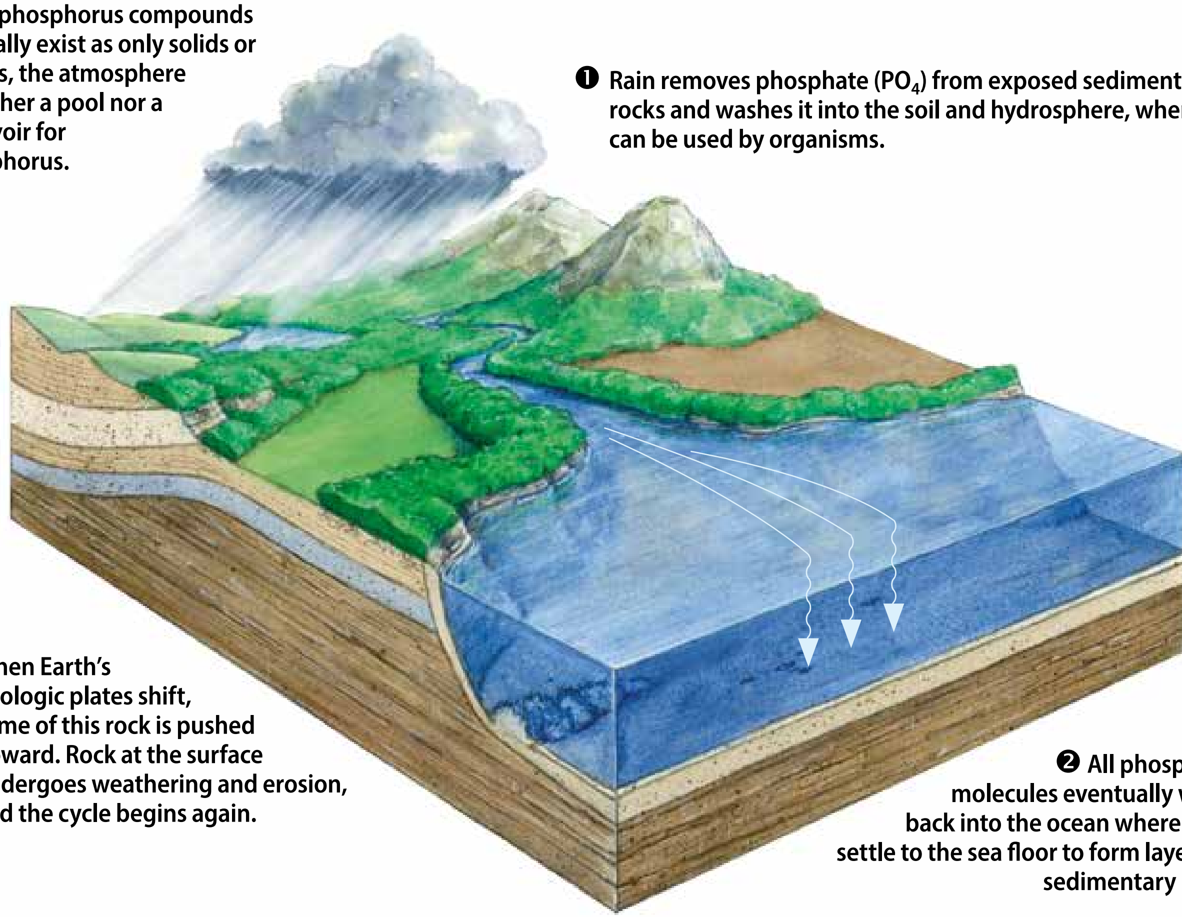
At Earth's normal temperatures and pressures, phosphorus compounds exist only as solids and liquids. Therefore, the atmosphere is neither a pool nor a reservoir for phosphorus. The largest reservoir of phosphorus occurs in sedimentary rocks in the Earth's crust. Rain removes phosphorus in the form of phosphate (PO_4) from these rocks and washes it into the soil and hydrosphere, where it can be used by organisms.

Phosphorus moves into food chains when plants absorb phosphate through their roots. Other organisms obtain phosphorus by eating plants or other organisms. Decomposers return phosphates to the soil by breaking down dead organisms or the wastes that organisms produce.

In some soils, plants cannot absorb phosphate by themselves and must team up with fungi to get the phosphorus they need. In this mutualistic relationship, called **mycorrhizae**, plants provide fungi with carbohydrates. In return, fungi gather phosphates and other nutrients with their vast network of **mycelia**, tiny, thread-like organs that gather water and nutrients.

All phosphate molecules eventually wash back into the ocean where they settle to the sea floor and form layers of sedimentary rock. When Earth's geologic plates shift, some of this rock is pushed upward. Rock at the surface undergoes weathering and erosion, and the cycle begins again.

FIGURE 7.5—THE PHOSPHORUS CYCLE



Nitrogen gas makes up 78 percent of the air we breathe, but few organisms can use nitrogen in this form.

THE NITROGEN CYCLE

Nitrogen is an essential part of DNA, RNA and amino acids. It helps form chlorophyll, the green pigment involved in photosynthesis. The major reservoir of Earth's nitrogen is the atmosphere. In fact, 78 percent of the air we breathe is composed of nitrogen gas (N_2). Few organisms can use nitrogen in this form, however. Instead, it must undergo a process called **nitrogen fixation**, which changes nitrogen gas into ammonia (NH_3) *(Figure 7.6)*. Nitrogen can be fixed in three different ways:

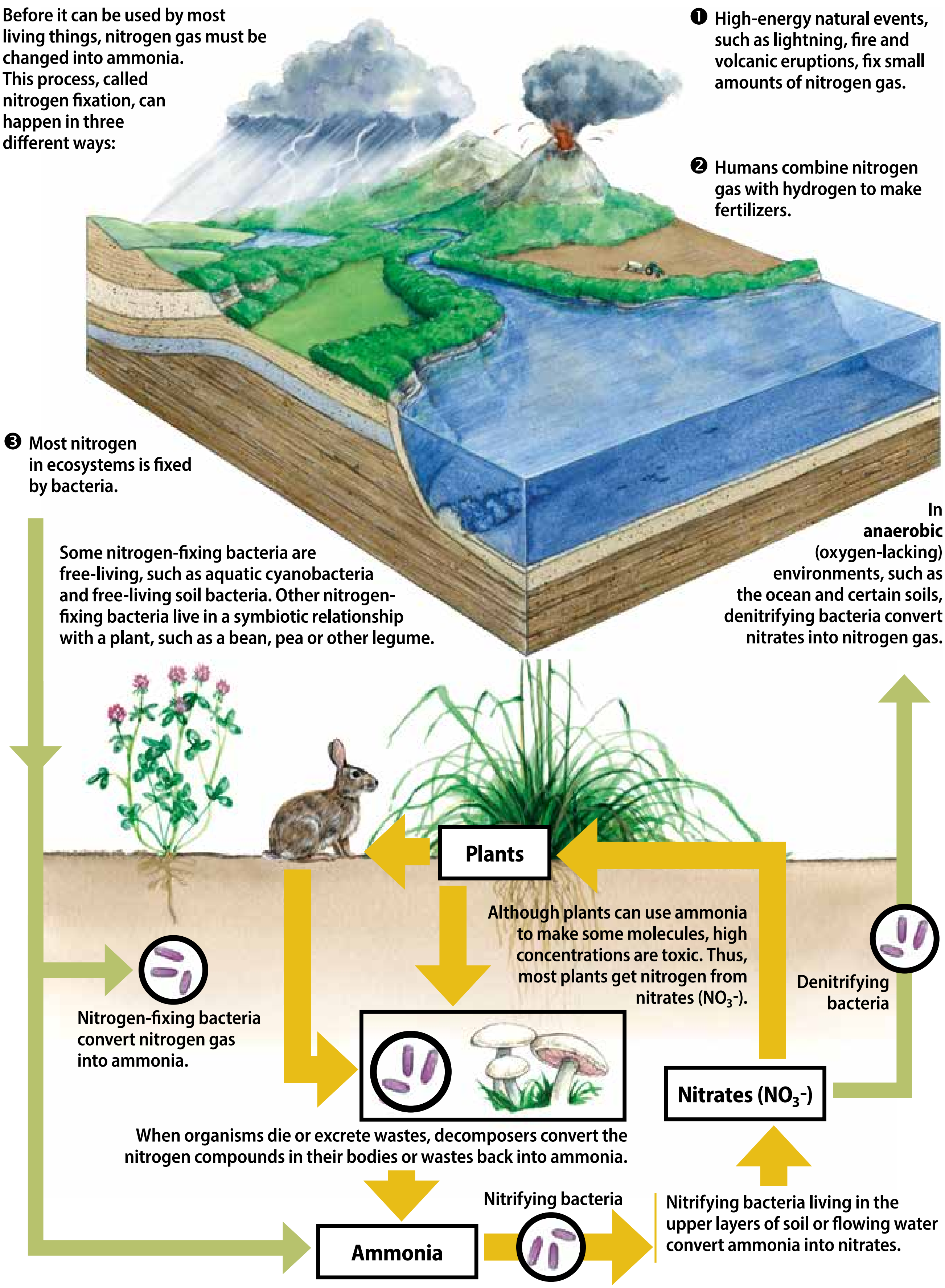
- High-energy natural events, such as lightning, fire and volcanic eruptions, fix small amounts of nitrogen gas.
- Humans combine nitrogen gas with hydrogen (usually a byproduct from fossil fuels) to make nitrogen-based fertilizers.
- Most nitrogen in ecosystems is fixed by bacteria. Some nitrogen-fixing bacteria are free-living, such as aquatic cyanobacteria and free-living soil bacteria. Other nitrogen-fixing bacteria live in a symbiotic relationship with a plant, such as a bean, pea or other legume. In this relationship, the plant provides bacteria with carbohydrates to fuel nitrogen fixation, and the bacteria provide the plant with a useable form of nitrogen.

Plants can use ammonia to make proteins and other nitrogen-based molecules. High concentrations of ammonia, however, are toxic. Because of this, most plants get nitrogen from nitrates (NO_3^-). A different kind of bacteria, nitrifying bacteria, convert ammonia into nitrates through a process called **nitrification**. Nitrification requires oxygen, so it only happens in oxygen-rich environments, such as upper layers of soil or flowing water.

Once nitrogen is incorporated into plant tissues, it can travel through food chains to other organisms. When organisms die or excrete wastes, decomposers convert the nitrogen compounds in their bodies or wastes back into ammonia.

Ammonia sticks to soil particles and stays put. In contrast, nitrates dissolve in water and can wash out of the soil into the hydrosphere, where they eventually end up in the ocean. Here, in **anaerobic** (oxygen-lacking) environments, denitrifying bacteria convert nitrates into nitrogen gas. This process, called **denitrification**, also occurs in anaerobic soils. Denitrification removes nitrogen from the biosphere, geosphere and hydrosphere and returns it to the atmosphere.

FIGURE 7.6—PHYSICAL AND BIOLOGICAL COMPONENTS OF THE NITROGEN CYCLE

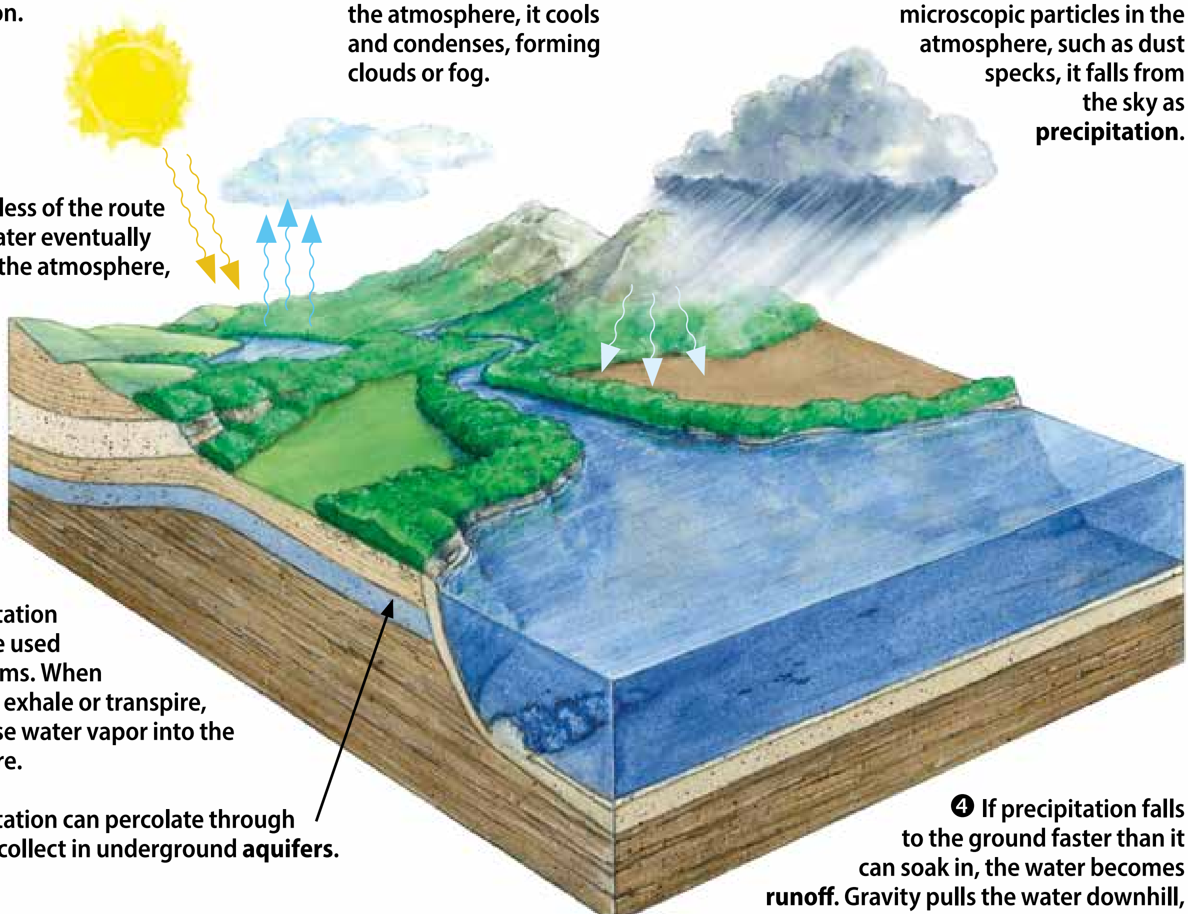


THE WATER CYCLE

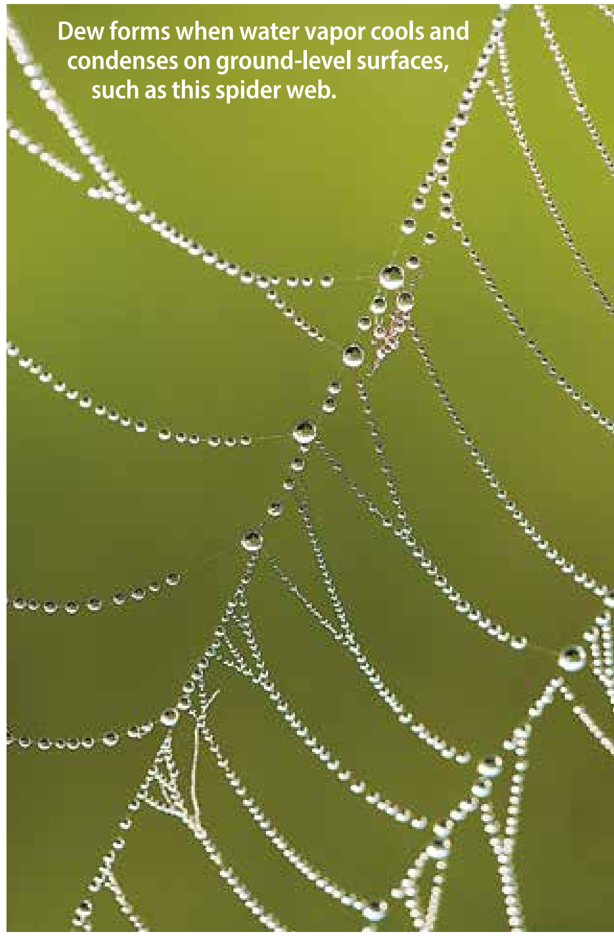
Although water is a molecule—not an element—it is one of the most important ingredients of life. Water-based fluids, such as blood and cytoplasm, play a vital role in transporting substances throughout the bodies of organisms. Water keeps the internal temperature of many organisms from changing too rapidly when the ambient temperature changes. For many organisms, including earthworms, jellyfish and plants, water is a supporting structure. (This is why plants wilt when they lose too much water.) Water plays a role in reproduction. For a sperm to fertilize an egg, for example, it must travel through water-based fluids. Water is a reactant or product in many chemical reactions that occur inside organisms, including photosynthesis and cellular respiration. In addition, water is a key habitat component for a vast array of organisms, from bacteria to bluegills.

The Earth contains enough water to fill about 700,000,000,000,000,000,000 two-liter soda bottles. More than 97 percent of this water resides in the oceans, rivers and lakes of the hydrosphere. About 2.9 percent is found in the geosphere, either frozen in polar ice caps and glaciers, contained in soil, or pooled in underground aquifers. Water vapor in the atmosphere accounts for 0.001 percent of Earth's water. Living organisms—which make up the biosphere—contain a scant 0.00008 percent of Earth's water. The movement of water among these different spheres is called the **water cycle** *(Figure 7.7)*.

FIGURE 7.7—THE WATER CYCLE



Because water is composed of oxygen and hydrogen atoms, the water cycle is an important way that oxygen and hydrogen move through ecosystems and become available to living organisms. Some water moves between the biosphere and other spheres through the chemical reactions that occur inside organisms. Most of the water cycle, however, is driven by two physical factors—solar energy and gravity.



Dew forms when water vapor cools and condenses on ground-level surfaces, such as this spider web.

The sun warms water on the Earth's surface and changes it into water vapor. This change of state—from liquid to gas—is called **evaporation**. Evaporation moves water from the geosphere and hydrosphere to the atmosphere. Living organisms can also move water to the atmosphere. Every time you exhale, you breathe out water vapor. Plants release water vapor into the atmosphere through their stomata, which are microscopic pores in the plant's leaves and stems. This process, called **transpiration**, helps plants release excess water resulting from photosynthesis and cellular respiration. Transpiration also helps cool the plant when temperatures are high.

As water vapor rises in the atmosphere, it cools and changes back into liquid, forming clouds or fog. This change of state—from gas to liquid—is called **condensation**. Water vapor also condenses on ground-level surfaces as dew. When water vapor condenses on microscopic particles in the atmosphere, such as dust specks, it can fall from the sky as **precipitation**. Condensation and precipitation move water from the atmosphere to the hydrosphere and geosphere.

Precipitation falling on land can take several routes through an ecosystem. It can be taken up by organisms, in which case it is eventually exhaled or transpired as water vapor. It can percolate through soil and other porous surfaces, where it can be absorbed by the roots of plants or collect in **aquifers**, underground pools in the pores and crevices of bedrock. If precipitation falls to the ground faster than it can soak in, the water becomes **runoff**. Gravity pulls the water downhill, where it eventually evaporates or collects in streams, rivers, lakes or oceans. Regardless of the route it takes, water eventually returns to the atmosphere, and the whole cycle begins again.

Human populations affect element cycles.

Because of gravity and the conservation of matter, the Earth is a closed system. When atoms move out of one pool or reservoir, they must reside in another. Historically, natural events such as volcanic eruptions, meteorite strikes or changes in the Earth's orbit have altered how atoms are distributed. Within the last 200 years—the blink of an eye in geologic time—human activity has become another significant force changing the distribution of atoms in Earth's various pools and reservoirs. This has important consequences for humans and other organisms.

Human activity has increased the amount of nitrogen and phosphorus in the biosphere. To make fertilizers, humans mine phosphorus from the geosphere and fix nitrogen from the atmosphere. Fertilizers are applied to lawns, golf courses and crop fields to increase plant growth. Too much fertilizer, however, can lead to **eutrophication**, which devastates biological communities. Eutrophication occurs when large amounts of fertilizers run off the land into watersheds. The build-up of nitrogen and phosphorus in rivers, lakes and oceans, stimulates the growth of enormous amounts of algae, aquatic plants and other producers.


Humans use six times more water today than they did 100 years ago.

When these organisms die, decomposition removes oxygen from the water. Without adequate oxygen, other aquatic organisms die, causing the aquatic ecosystem to collapse. Human sewage and industrial wastes also cause eutrophication.

Through deforestation and the burning of fossil fuels, humans move enormous quantities of carbon into the atmosphere. Carbon-based gases, such as carbon dioxide and methane, are known as **greenhouse gases** because they allow sunlight to pass through but trap heat—just like the panels of a greenhouse. Without greenhouse gases, the Earth's average surface temperature would be minus 17 degrees Celsius—too cold for life to flourish. As greenhouse gases build up in the atmosphere, however, temperatures are increasing at rates that alarm some scientists.

According to climate scientists around the world, in the last 100 years, Earth's average temperature has increased by 0.7 to 0.8 degrees Celsius. If greenhouse gases continue to increase, models predict Earth's temperature could increase by 1.8 to 4.0 degrees Celsius by the end of this century. These models are imprecise, however, and scientists are unsure how fast climate change will occur and how warming will affect earth's ecosystems.

Humans affect the distribution of water through consumption and pollution. Water is used to irrigate crops, water livestock, produce goods, and for drinking, cooking and washing. From 1900 to now, the human population has doubled, but we use six times the amount of water! In fact, humans use so much water in some parts of the world that we've drained rivers dry, and we've pumped so much water out of underground aquifers that the ground has sunk in certain areas. Sewage and industrial wastes pollute water, making it unusable to humans and other organisms. All of this has led to water shortages throughout the world, which affect the survival not only of humans, but of all organisms. Unless solutions are quickly implemented, global water shortages and climate change could reshape Earth's ecosystems, profoundly affecting biological communities and the economies, politics and stability of human societies. ▲

Keeping Harmful Elements Out of Ecosystems

During a typical dove season at Columbia Bottom Conservation Area, hunters shoot about 32,000 shotgun shells, each containing an average of one ounce of shot. This works out to 2,000 pounds—a ton—of shot deposited on the ground each year. Lead shot is banned at Columbia Bottom. Instead, hunters must shoot shells filled with steel or other types of nontoxic shot. Why?

When foraging for food, doves, waterfowl and many other birds swallow pieces of grit and gravel. The pebbles are stored in a muscular stomach called the gizzard. Birds don't have teeth and can't chew and grind up food. That's where the gizzard comes in. When the gizzard contracts, the pebbles inside pulverize hard foods like seeds, nuts and invertebrates, making them easier to digest.

To a bird, a lead shotgun pellet looks like any other bit of rock it might eat to keep its gizzard stocked. When the lead reaches the gizzard it is worn down, dissolved and absorbed into the body. Lead, however, is toxic in even small concentrations and causes irreparable bone, nerve and muscle damage. Studies have shown that up to 6 percent of the doves feeding at Columbia Bottom could die from lead poisoning each year if nontoxic shot were not required for hunting.

Lead poisoning is a terrible way to die. When a bird ingests too much lead, it gets weak, loses weight, and eventually becomes paralyzed. Many birds starve to death. Others become so weak they make easy pickings for predators. Some birds, particularly waterfowl, drown when they cannot hold their heads above water. Studies reveal that 31 species of birds can fall victim to lead poisoning.

Lead can work its way up the food chain and kill other animals, too. Lead poisoning has been found in raccoons, mink and birds of prey. Between 1994 and 2003, the Wisconsin Department of Natural Resources examined 559 dead bald eagles. The researchers found that 68 of the eagles—12 percent—had died from lead poisoning.

In 1990, the Conservation Department banned the use of lead shot for waterfowl hunting in Missouri. A year later, lead shot for waterfowl hunting was banned nationwide. In 2007, Missouri expanded its lead shot ban to include all types of shotgun hunting on 21 of Missouri's conservation areas. These areas have extensive wetlands and large concentrations of doves, waterfowl and shorebirds.

The U.S. Fish and Wildlife Service estimates that prior to 1991, 1.6 to 2.4 million waterfowl died *each year* from lead shot poisoning. Now, thanks to the use of nontoxic shot, those numbers are much lower.

A hunter harvests a mourning dove.

A researcher untangles a live songbird from a mist net in an Ozark forest. The kinds of birds found in the net, along with other data, will help the researcher assess the number and variety of organisms that live in the forest.

BIG IDEAS:

- Ecologists use species richness and relative abundance to measure and compare biological communities.
- Biodiversity refers to the variety of genes, species and ecosystems in a given area.
- Biodiversity is affected by latitude, habitat complexity and area.
- The species richness of a community is a balance between immigration and extirpation.
- Communities undergo a sequence of predictable changes following a disturbance.
- Early and late successional species have different adaptations.

DIVERSITY AND DISTURBANCE OF Biological Communities

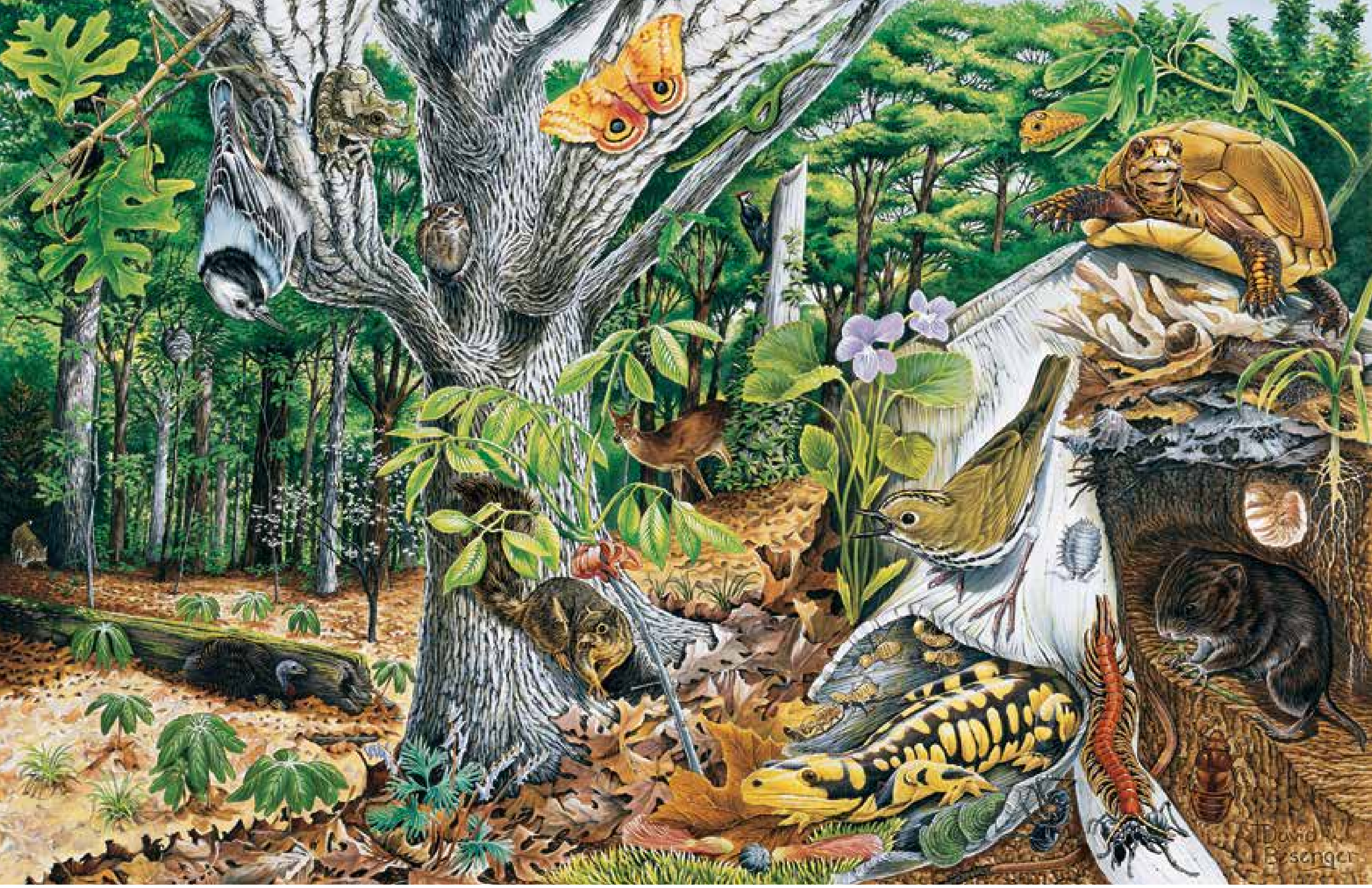
In seconds, the chainsaw chewed through 70 years of growth. When he saw the massive oak begin to lean, the logger stepped nimbly to one side. Gravity finished the job, pulling three tons of tree to a limb-snapping, ground-shuddering finish.

For the lumberjack, it was just another day of logging at Peck Ranch Conservation Area. For the ecologist watching nearby, it was the beginning of an unprecedented study. Unlike most ecological studies, which typically span two or three years, the Missouri Ozarks Forest Ecosystem Project is scheduled to run for 100 years.

Work on this project began in 1991 when crews of ecologists, conservationists and college students scoured 3,700 hectares of Ozark forest to gather baseline data. Crews tallied trees in the canopy, counted plants in the understory and inventoried insects crawling on the forest floor. Some crews focused on amphibians, birds and mammals. Others measured abiotic components of the forest, such as soil types and climate. All this information painted a detailed portrait of the forest at a particular point in time.

With that snapshot in their photo album, researchers began harvesting trees in different parts of the forest. In some areas, all the trees were cut. In other areas, some trees were cut while others were left standing. In still other areas, no trees were cut at all.

Over the next ten decades, scientists will gather terabytes of data about how organisms react to these harvests and others yet to come. Their work will add volumes to what we currently know about the structure and function of biological communities. In this chapter, we will learn how ecologists measure and compare communities, investigate factors that affect the number and variety of organisms making up a community, and explore how communities change over time.



A forest community is shared by many coexisting populations.

Ecologists use species richness and relative abundance to measure and compare biological communities.

Every place on earth—each marsh, each prairie, each leaf at the tip of a white oak—is shared by many coexisting populations. They form what ecologists refer to as a **biological community**, a group of populations that live and interact in the same place at the same time. Organisms within a community are linked together by the flow of energy in food webs and the cycling of elements. Organisms compete with, exploit and help each other. In doing so, they affect the size of their own population and other populations.

Even the simplest biological communities contain overwhelming numbers of species. A handful of dead leaves collected from an Ozark forest might contain more than 65 different kinds of insects, spiders and mites, not to mention hundreds of different microscopic fungi, protists and bacteria. In addition, the movements of animals, seeds and organic material link biological communities together, making it nearly impossible to determine where one community ends and another begins. To manage this complexity, ecologists often study subsets of biological communities, focusing, for example, on the plant community in a 9,000-hectare forest, the fish community in a kilometer of the Jack's Fork River, or the insect community living in a single bur oak.

Ecologists study a community's **structure**, the living organisms it is composed of, and **function**, how those organisms interact to sustain the community. One of the most revealing measures of a community's structure is the number of species it contains. Ecologists call this measurement **species richness**.

Imagine sampling the tree species in one hectare of Ozark forest. Each time we encounter a new kind of tree, we record it on a data sheet. When we've finished sampling, we have recorded the tree species listed in the first column of Table 8.1. To determine the species richness of our sample, we simply count the number of

Species	Number of Individuals	Percentage
Scarlet oak	63	25.00%
Black oak	38	15.00%
Hickory	20	8.00%
White oak	20	8.00%
Flowering dogwood	18	7.00%
Shortleaf pine	16	6.50%
Red maple	15	6.00%
Eastern red cedar	13	5.00%
White ash	10	4.00%
Wild cherry	10	4.00%
Sycamore	10	4.00%
Cottonwood	8	3.00%
Sassafras	8	3.00%
American elm	3	1.00%
American basswood	1	0.50%
TOTAL	250	100.00%

Table 8.1—Species Richness and Relative Abundance of Trees in an Ozark Forest

species we have recorded, in this case, 15. Species richness, however, describes only part of a community's structure. To obtain the full picture, we need to count how many individuals of each species are in our sample area. This measurement, shown in the second column of Table 8.1, is called **relative abundance** or **species evenness**. Relative abundance shows how *abundant* one species is *relative* to all the others in a community. It is often expressed as a percentage. In our sample, scarlet oak has a relative abundance of 25 percent of the trees, while American basswood has a relative abundance of less than 1 percent.

When we look closely at Table 8.1, an interesting pattern emerges. We see that a few species, such as scarlet oak and black oak are extremely abundant. We also notice that a few species, such as American elm and basswood, are extremely rare. The majority of trees—everything from hickory to sycamore—are moderately abundant. If we were to plot this on a graph, it would show a bell-shaped curve similar to Figure 8.1. Nearly all communities show this pattern of relative abundance. Whether we sample trees in an Ozark forest or fish in an Indonesian coral reef, we would find that most species are moderately abundant, while few are very abundant or extremely rare.

Ecologists have found that the more you sample a specific community, the more species you will find. Common and abundant species turn up in small samples, but a great deal of effort and a large sample is needed to find the rarest species. As a result, only large samples produce a full bell-shaped curve.

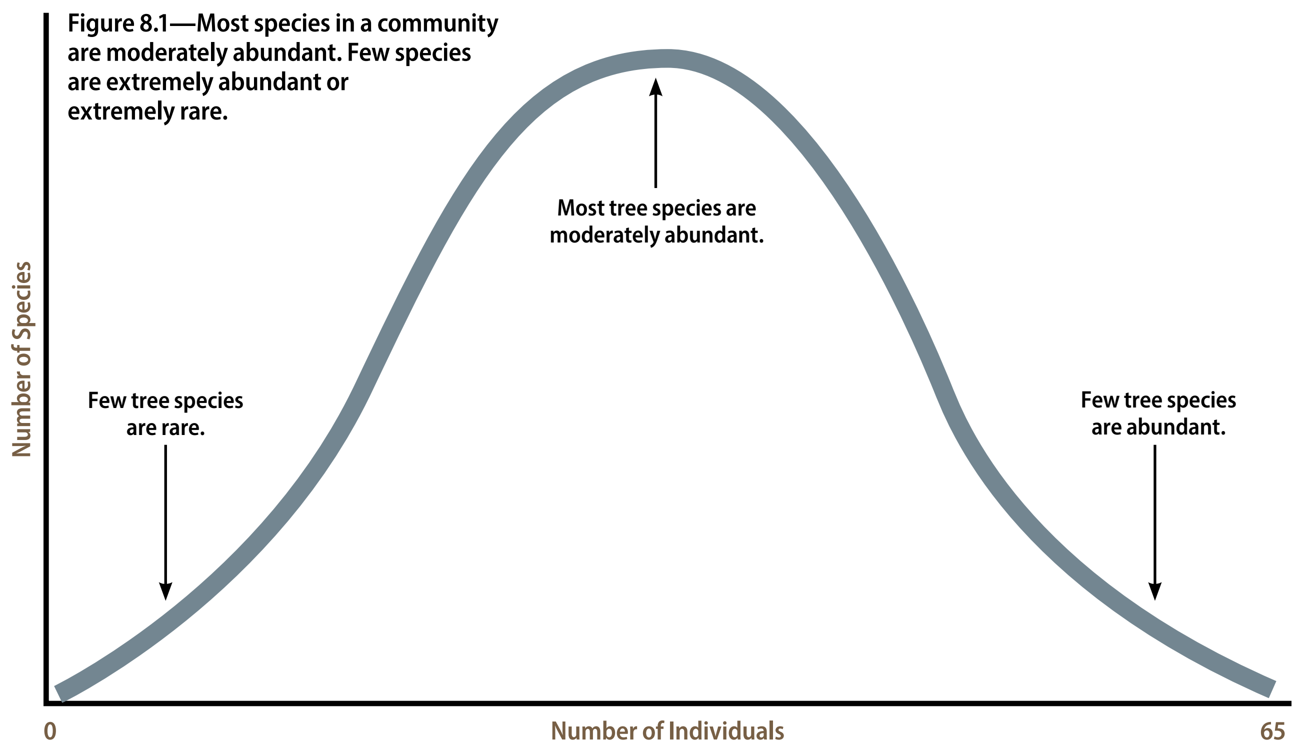
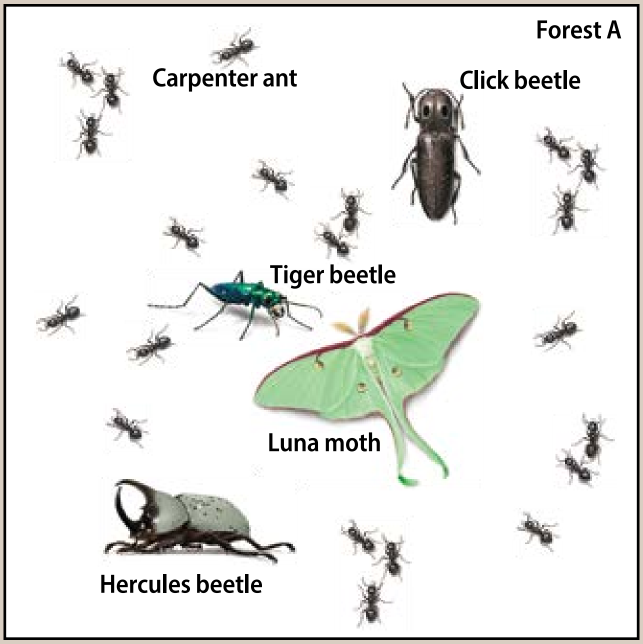
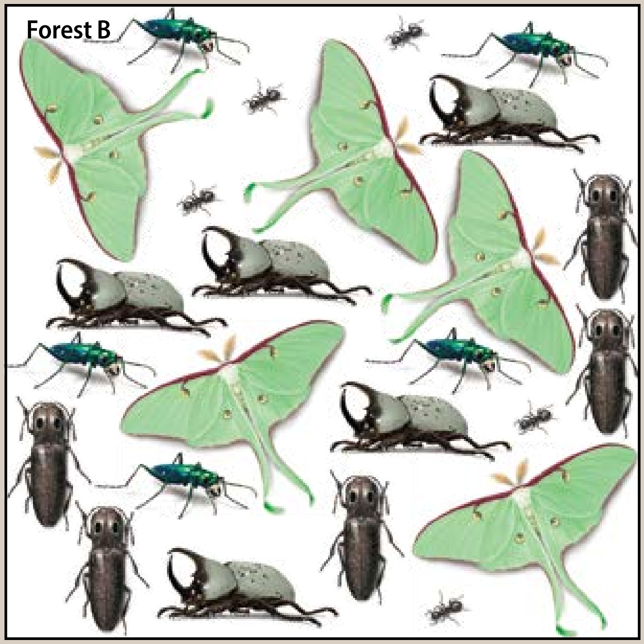


Figure 8.1—Most species in a community are moderately abundant. Few species are extremely abundant or extremely rare.

Figure 8.2—A Comparison of Insect Communities in Two Forests





Taken together, species richness and relative abundance give an impression of the variety of life that exists in a community. To illustrate the relationship between species richness and relative abundance, let's compare the insect communities in two different forests *(Figure 8.2)*.

Both forests contain five different insect species, so they have equal amounts of species richness. In Forest A, however, carpenter ants have a relative abundance of 84 percent, while each of the other insect species makes up only 4 percent of the community. In Forest B, all five species are equally abundant, each making up 20 percent of the community. If we were to walk through each forest, we would probably notice that Forest B seems to have more variety than Forest A. Ecologists use **diversity indices** to quantify this impression.

A commonly used diversity index is the Shannon-Wiener index. Here's the equation:

$$H' = -\sum p_i (\log_e p_i)$$

H'	=	the value of the Shannon-Wiener index
p_i	=	the proportion of each species
$\log_e$	=	the natural logarithm

Don't let this equation scare you! A Shannon-Wiener index isn't hard to calculate once you know how to do it. Just follow these steps:

1. Determine the proportions of each species in the community. To do this, take the number of individuals in one species and divide by the total number of individuals in the entire sample. There are 21 carpenter ants in Forest A and 25 total individuals in Forest A. Thus, $21 \div 25 = 0.84$. Do this for every species.
2. Multiply each proportion from step 1 by its natural logarithm. A scientific calculator comes in handy, here. For carpenter ants, type 0.84 into your calculator and push the key marked "ln" or "$\log_e$." You should get a value of -0.174. Do this for every species.
3. Multiply the proportion for each species by the value you calculated in step 2. For carpenter ants we would multiply 0.84 by -0.174 for a value of -0.146. Do this for every species.
4. Add together each of the values from step 3. For the species in Forest A, we would calculate this value like this: $-0.146 + -0.129 + -0.129 + -0.129 + -0.129 = -0.662$.
5. The number you arrive at in step 4 will be a negative number. The Shannon-Wiener index calls for taking its opposite. Thus, -0.662 becomes 0.662.

Forest A

Species	Number	Proportion (p_i)	$\log_e p_i$	$p_i \log_e p_i$
Carpenter Ant	21	0.84	-0.174	-0.146
Luna Moth	1	0.04	-3.219	-0.129
Tiger Beetle	1	0.04	-3.219	-0.129
Click Beetle	1	0.04	-3.219	-0.129
Hercules Beetle	1	0.04	-3.219	-0.129
TOTAL	25	1.00		-0.662

H' = 0.662

Forest B

Species	Number	Proportion (p_i)	$\log_e p_i$	$p_i \log_e p_i$
Carpenter Ant	5	0.20	-1.609	-0.322
Luna Moth	5	0.20	-1.609	-0.322
Tiger Beetle	5	0.20	-1.609	-0.322
Click Beetle	5	0.20	-1.609	-0.322
Hercules Beetle	5	0.20	-1.609	-0.322
TOTAL	25	1.00		-1.610

H' = 1.610

Table 8.2—The Shannon-Wiener index has been calculated for Forest A (top) and Forest B (bottom). Notice that Forest B has a higher index and, therefore, more species diversity.

In a community with one individual, H' (the Shannon-Wiener index) would be 0. The value of H' increases as species richness and relative abundance increase. Thus, higher values of H' indicate more variety or **species diversity** in a community. Table 8.2 calculates the Shannon-Wiener index for our two insect communities. You'll notice that Forest B has a higher index. This is because the relative abundance of the insects in Forest B are more evenly distributed.

Biodiversity refers to the variety of genes, species and ecosystems in a given area.

Missouri is a biological melting pot. Within our state's borders roam about 70 different kinds of mammals, more than 400 species of birds, and over 100 species of amphibians and reptiles. No region of the world has a more diverse mix of freshwater fishes—nearly 200 species cruise our state's streams, rivers and lakes. An estimated 18,000 different kinds of insects flutter, buzz, burrow, swim and scurry through Missouri. More than 20 different kinds of oak trees help make up over 2,500 different kinds of plants that grow here. New species turn up every year.

Ecologists have barely recorded all the plants, animals and fungi that live in Missouri, let alone throughout the world. Nearly 1.5 million species have been described and named worldwide. Ecologists estimate that more than 10 million species likely exist on Earth *(Figure 8.3)*. These species make up the biological diversity, or **biodiversity**, of our planet. Biodiversity is made up of three components:

- Species diversity refers to the species richness and relative abundance found in a certain area.
- Genetic diversity is the variety of genotypes found among individuals in a population. This is a critical component of biodiversity, because, as we learned in chapter two, high genetic diversity allows a species to adapt to changing environments.
- Ecosystem diversity refers to the variety of different ecosystems that exist within a larger region such as a landscape or watershed.

Biodiversity is often used to mean species richness. Regardless of how precisely the term is used, biodiversity offers an important yardstick to measure and compare different biological communities. This helps ecologists determine which areas support the greatest number of species, which areas would make good nature preserves, and which areas might provide habitat for rare or endangered species.

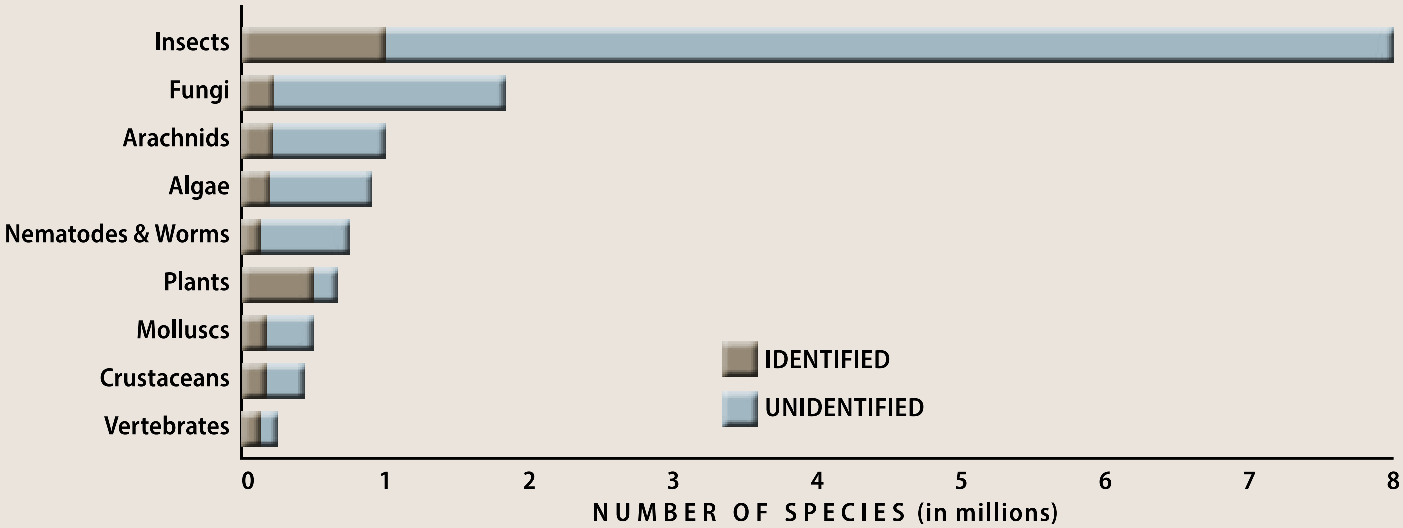


Figure 8.3—Estimated Worldwide Species Richness for Various Groups of Organisms
(Data from Millennium Ecosystem Assessment, 2005, World Resources Institute)

Species in a community interact with and depend upon each other in many ways. As a result, the loss of one species can bring about the loss of others. High biodiversity helps stabilize biological communities and helps communities recover from environmental change or human disturbance. Ecologists have shown that ecosystems—whether forests, prairies or wetlands—recover faster from droughts, fires, diseases and other natural disasters if they harbor many species rather than just a few. This is why preserving areas of high biodiversity has become a priority for conservationists throughout the world.

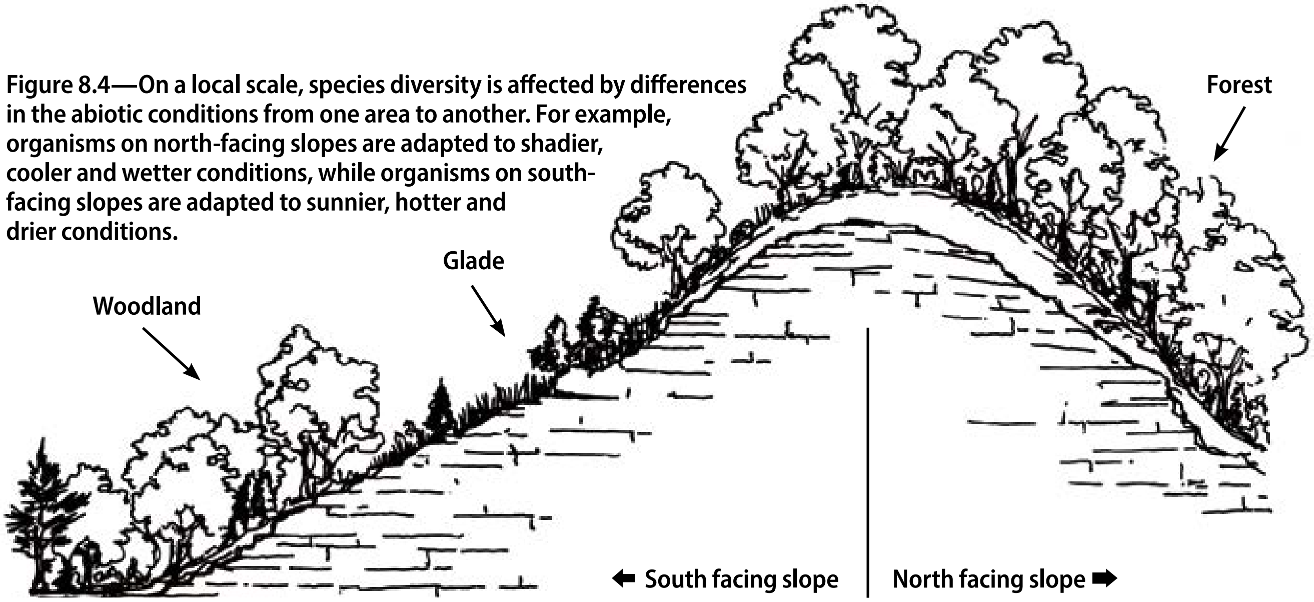
Before European settlement, Missouri's biodiversity remained relatively stable for thousands of years. Over the last two centuries, however, human activity has drastically altered our state's biodiversity. During this time, we have destroyed habitats, introduced invasive species and hunted other species to the point of extinction. Our history is mirrored by what is happening worldwide. As many species become rare or extinct—some even before they've been cataloged by scientists—ecologists feel an urgent need to understand why some communities have more biodiversity than others and find ways to preserve as many species as possible.

Biodiversity is affected by latitude, habitat complexity and area.

Different areas—even areas separated by just a few hundred meters—may vary greatly in the number and variety of species that live there. On the northeast side of an Ozark hill, we might find plants and animals adapted to shady, relatively wet conditions, such as white and red oaks, shortleaf pines, flowering dogwoods, tiger salamanders, pileated woodpeckers and flying squirrels. If we were to walk over the ridge to the southwestern side of the hill, we would likely find animals adapted to sunnier and drier conditions. Here we might encounter grasses, such as little bluestem, Indian grass and sideoats grama, collared lizards, roadrunners and scorpions *(Figure 8.4)*. This raises an important question: Why do communities differ in the biodiversity they contain?

On a local scale, differences in the number and variety of species occur because different areas have different abiotic conditions. Because it is shaded from hot afternoon sunshine, the northeastern side of an Ozark hill has lower temperatures and lower evaporation rates than the southwestern side. Thus, the abiotic properties of a northeastern hillside meet the niche requirements of organisms adapted to cooler, wetter and shadier conditions. Likewise, the abiotic properties of the southwestern hillside satisfy the niche requirements of organisms adapted to hotter, drier and sunnier conditions.

Figure 8.4—On a local scale, species diversity is affected by differences in the abiotic conditions from one area to another. For example, organisms on north-facing slopes are adapted to shadier, cooler and wetter conditions, while organisms on south-facing slopes are adapted to sunnier, hotter and drier conditions.



If we examine biodiversity on a regional or global scale, other patterns emerge. Explorers and naturalists of the 19th century, including Charles Darwin and Alfred Wallace, were astounded by the vast array of life they found in the tropics. A century later, ecologists began to compare species richness in the tropics to other latitudes. They found that with most groups of organisms—from mammals to microbes—species richness increases toward the equator. For example, the boreal forests of Manitoba, Canada are home to about 320 species of birds, Missouri has 403 species, Costa Rica has 857, and the rain forests of Colombia contain an astonishing 1,871. Other vertebrates follow this trend *(Figure 8.5)*.

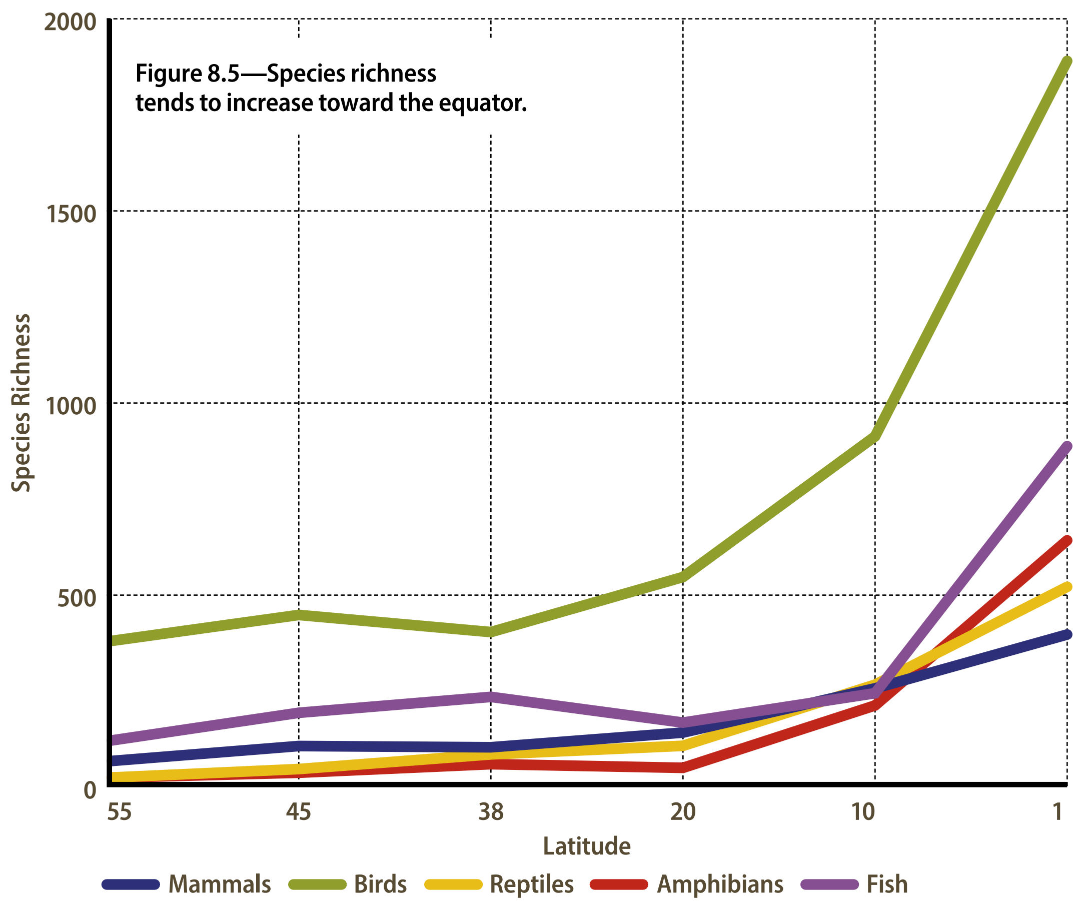


Figure 8.5—Species richness tends to increase toward the equator.

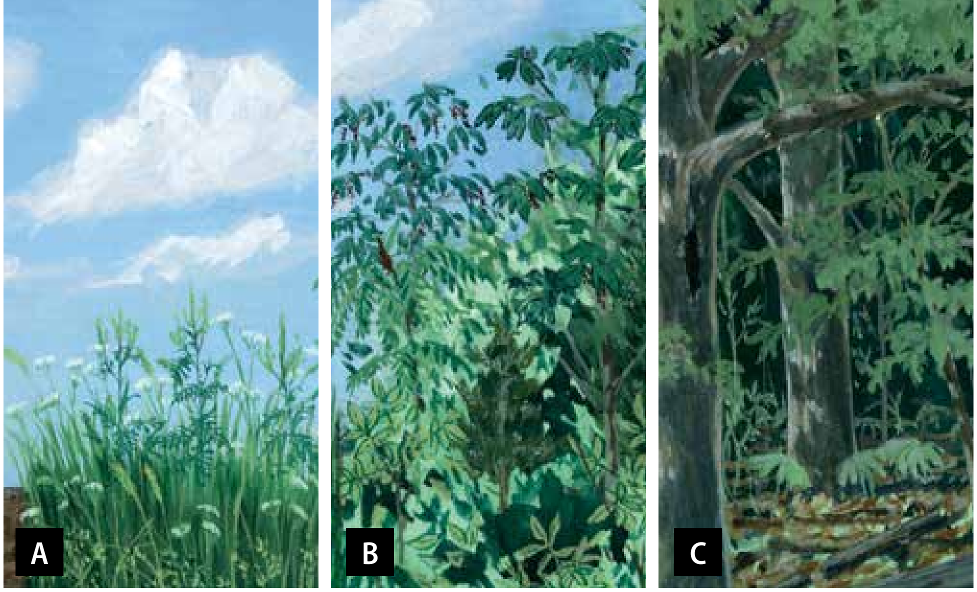


Figure 8.6—Ecosystems with more vertical layers of vegetation harbor a greater diversity of birds. Prairies (A), with a single layer of vegetation, contain fewer bird species than shrubby fields (B), which have two vegetation layers. Likewise, shrubby fields contain fewer species than forests (C), which have three vegetation layers.

Another interesting pattern is that biodiversity is higher in complex ecosystems compared to simple ecosystems. Robert and John MacArthur compared bird diversity in different habitats, including grasslands, shrubby fields and deciduous forests. The ecologists found that habitats with more vertical layers of vegetation contained a greater diversity of birds. For example, prairies, which have a single vegetation layer, contain fewer bird species than deciduous forests, which have ground, understory and canopy vegetation layers (Figure 8.6). They reasoned that more layers of vegetation provide more niches for a greater diversity of species. This relationship holds up for a number of different organisms and habitats. Coral reefs, for example, have a complex structure that supports far more fish species than the open ocean, which is structurally simple.

As a general rule, large areas harbor more species than small areas. In 1921, the botanist Olaf Arrhenius quantified this relationship, which ecologists call the **species-area rule**. Since that time, ecologists have collected evidence to strengthen the species-area relationship. Many have examined the relationship between species richness and the size of islands in the ocean *(Figure 8.7)*. They found that relatively few species live on small islands while many more species live on larger islands. The species-area rule holds true not only for islands in the ocean, but also for islands of habitat, such as a forest surrounded by subdivisions or a lake surrounded by miles of dry land.

In contrast, a negative relationship often exists between an island's species richness and the distance it is from similar blocks of habitat. Islands that are isolated usually support fewer species than islands that are in close proximity to other islands. This relationship puzzled ecologists until the 1960s.

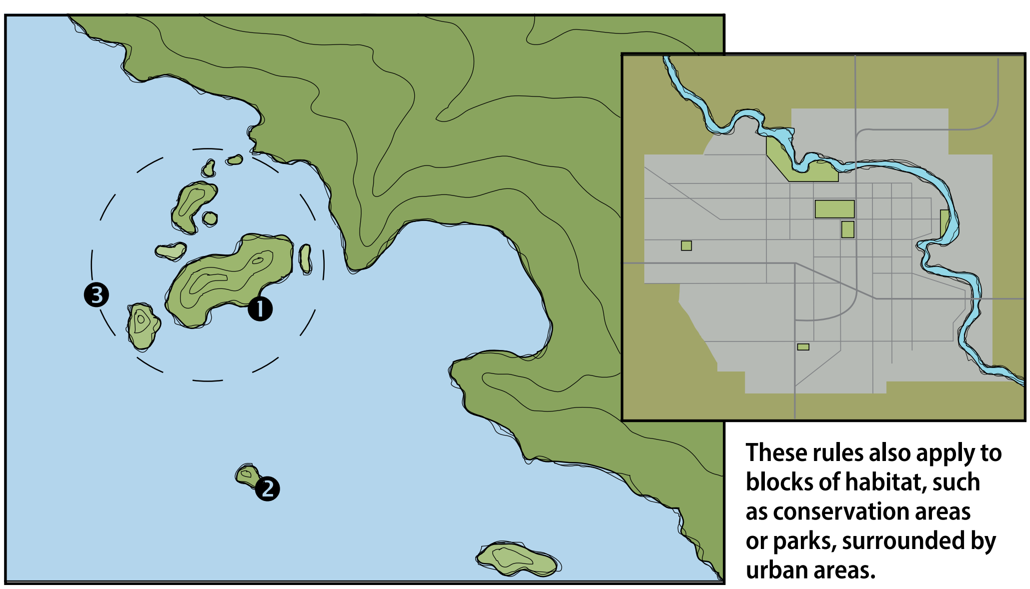


Figure 8.7—As a general rule, larger islands (1) support more species than smaller islands (2), and islands that are isolated (2) have fewer species than islands in close proximity to other islands (3).

These rules also apply to blocks of habitat, such as conservation areas or parks, surrounded by urban areas.

Missouri's Biodiversity Hotspots

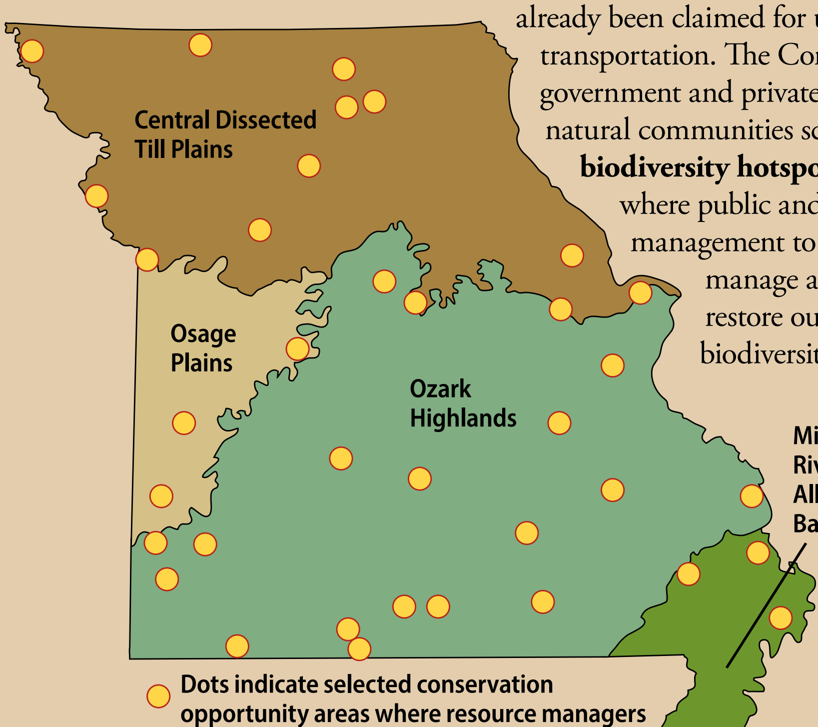
Humans are the ultimate keystone species. Our actions, both intentional and otherwise, profoundly affect ecosystems. We encourage and protect species we like, such as white-tailed deer, largemouth bass, purple coneflowers and white oaks. These organisms provide us with food, building materials and other economic resources, or they are simply pretty and fun to watch. But what about species we don't like or species that escape our attention because they are too small, too secretive or they inhabit places too remote? As we've learned throughout this book, these species also play a role in biological communities.

Traditionally, resource managers focused their efforts on specific species. Wildlife biologists managed habitats to increase populations of white-tailed deer, turkeys and other game animals. Foresters managed forests to increase yields of marketable trees for lumber, paper and other wood products. Fisheries biologists focused their efforts on fish anglers liked to catch. Management that focuses on specific species is called **featured-species management**.

In some cases, featured species management is still used. It's an important tool to maintain abundant, healthy populations of game animals and economically valuable plants. It's also critical to restore populations of rare and endangered organisms. In most cases, however, today's resource managers implement **community management**, focusing on entire biological communities rather than a few select species. Community management embraces the idea that all organisms are interconnected and interact within a community. As such, managers focus on nurturing conditions that maintain a community's structure and function. This may involve setting controlled fires to keep trees out of prairies, cleaning up streams, pumping water onto a wetland, or harvesting trees to mimic natural events such as forest fires and wind storms.

Ecologists divide Missouri into four large ecological regions. The Ozark Highlands is a region of forests, woodlands and glades cut by clear, spring-fed streams. Although now mostly farmland, the northern plains were formerly prairies and savannas dissected with wooded, muddy streams. The western border of Missouri lies at the edge of the Great Plains and represents our best remaining prairie communities. A century ago, Missouri's Bootheel was swampy and forested.

Not all locations within these regions are suitable for community management. Much land has already been claimed for urban areas, living space, food production and transportation. The Conservation Department, working with many government and private partners, has identified healthy, functioning natural communities scattered throughout each ecological region. These **biodiversity hotspots** or **conservation opportunity areas** are places where public and private conservation groups can use community management to protect, manage and restore our state's biodiversity.



Dots indicate selected conservation opportunity areas where resource managers focus their efforts to protect and restore Missouri's biodiversity.

Foresters manage Missouri's forest communities for a variety of things, including lumber.

The species richness of a community is a balance between immigration and extirpation.

How do we explain patterns of diversity? Why do some communities contain more species than others? What ecological processes might increase or decrease species richness? In the 1960s, Robert MacArthur and E.O. Wilson developed a now famous model to help answer these questions. They called it the **equilibrium model of island biogeography**.

MacArthur and Wilson proposed that species richness is a balancing act between immigration of new species into a community and extirpation of existing species from a community. Consider a forest in which we have experimentally removed every single bird. When we allow birds back into the forest, the rate of immigration will, at first, be extremely high, since every bird that immigrates into our forest will likely be a new species. As more and more birds show up, however, the immigration rate will go down because fewer and fewer arrivals will be new species *(Figure 8.8)*. In addition, as more birds show up, competition between species will increase. Some species will likely outcompete others, leading to competitive exclusion. Thus, as species richness increases, extirpation rates increase also *(Figure 8.9)*.

Figure 8.8—As species richness increases, the number of new species that turn up will decrease.

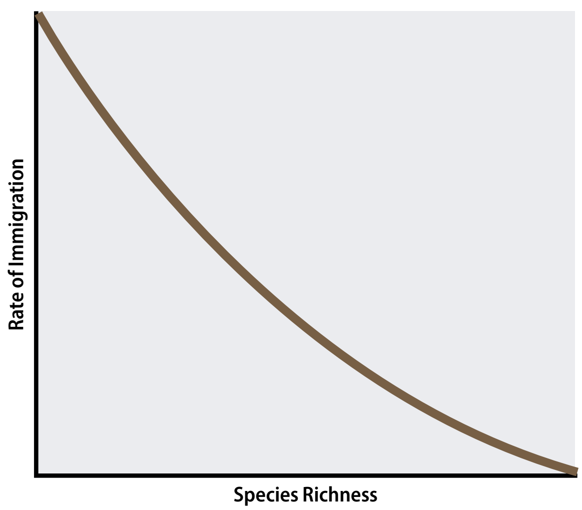


Figure 8.9—As species richness increases, the rate of extirpation also increases because more species are competing for the same resources.

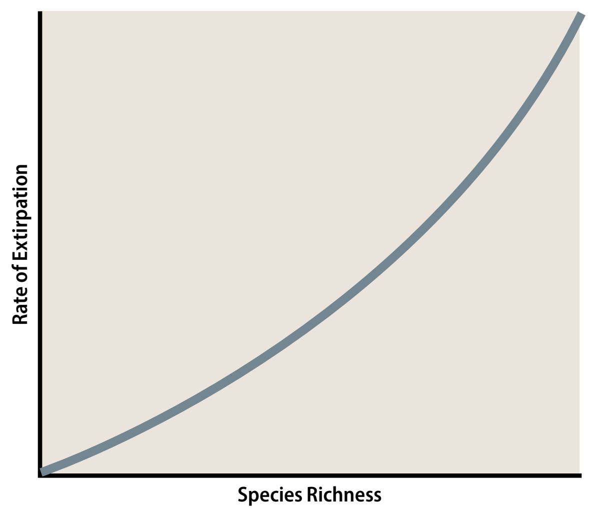


Figure 8.10—At the equilibrium point, the number of new species immigrating to an island is balanced by the number of species extirpated from the island.

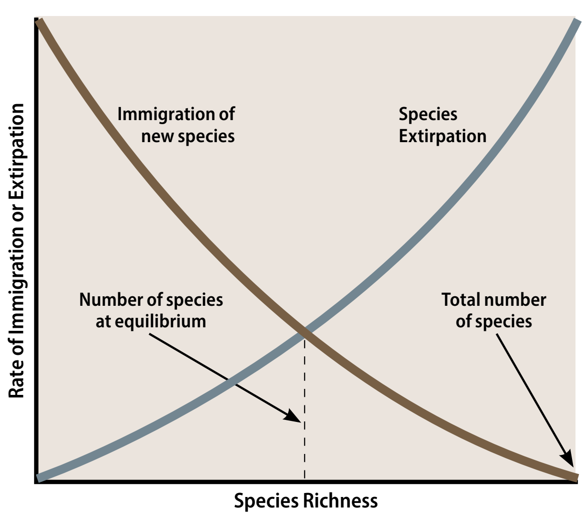
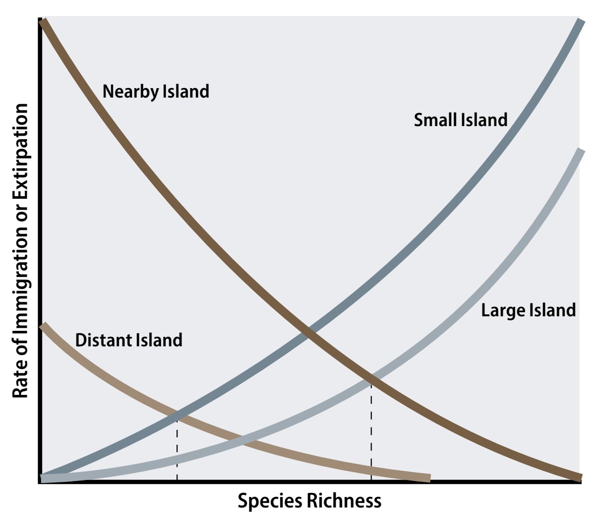


Figure 8.11—Small, distant islands have less species richness than large, nearby islands.



If you compare the two graphs, you'll notice that as species richness increases, the immigration rate falls and the extirpation rate rises. If we lay the two graphs over each other, the immigration rate and extirpation rate cross *(Figure 8.10)*. MacArthur and Wilson reasoned that the point where the two lines cross predicts the number of bird species that will occur in the forest. They called this the **equilibrium point** because at this level of species richness, the rate of immigration is balanced by the rate of extirpation.

MacArthur and Wilson proposed that a habitat's immigration rate is influenced mainly by its distance from a potential source of immigrants. Islands or blocks of habitat that are far from other blocks of similar habitat have lower immigration rates. Islands or blocks of habitat that are close to similar blocks of habitat have higher immigration rates. In contrast, MacArthur and Wilson proposed that an island's size is what mainly influences the rate of extirpation. They predicted that extirpation rates will be highest on small islands (or blocks of habitat) where resources are scarce and lowest on large islands where resources are plentiful. Thus, according to the equilibrium model of island biogeography, small, distant islands will have less species richness than large, nearby islands *(Figure 8.11)*.

Communities undergo a sequence of predictable changes following a disturbance.

To the casual observer, nothing seems to change in a community. A forest seems filled with the same oak trees and gray squirrels that were there last year or even 20 years before. Although some organisms die and others are born, oaks typically replace oaks and squirrels replace squirrels. A careful observer, however, will notice that communities are dynamic. When a community is disturbed—a forest logged, a prairie plowed, a marsh flooded—it changes in startling ways.

Imagine the Ozarks a hundred years ago. Both the Revolutionary and American Civil wars took a toll on our young democracy, and in the late 1800s the United States was struggling to rebuild. To do so, we needed lumber. To get it, logging companies flocked to the Ozarks. Clear Ozark streams became choked with sediment and long rafts of logged trees. Lumberjacks stood precariously atop the rafts, guiding them downstream to Grandin, a huge sawmill that needed about 30 hectares of trees *per day* to stay in business. To feed Grandin and other mills, hundreds of square kilometers of forests were recklessly logged. Eventually the trees ran out, the mills shut down, and the Ozark hills were left barren, with only a few tangles of briars hugging the rocky soil.

Following the lumber boom, the Ozark forests slowly rebuilt. Annual plants, such as ragweed and sunflowers, began growing almost before the last tree fell. Perennials, such as grasses and asters, sprang up the following year. Five years later, woody shrubs, such as blackberry and sumac, covered the hillsides. Within 20 years, young oaks and hickories formed dense thickets. And, in 70 to 100 years those trees had grown into the mature forests we see today.

During the logging boom in the late 1800s, Grandin sawmill in southern Missouri processed 30 hectares of trees daily.

This sequence of changes is called **succession**, or the replacement of one biological community by another over time. Ecologists recognize two types of succession. **Primary succession** begins on areas without soil, such as bare rock, lava flows and areas scraped lifeless by retreating glaciers. **Secondary succession** occurs when the preceding community is destroyed, but the soil is not. This kind of succession occurs after a farmed field is abandoned or a forest is logged.

Ecological disturbances cause secondary succession. **Disturbance**, to an ecologist, involves a departure from the typical environmental conditions of a community. There are many potential sources of disturbance. Abiotic forces, such as fires, tornadoes, ice storms and floods, create disturbance. Biotic factors, such as disease, pest outbreaks, predation and human activities, also can result in disturbance.

After a disturbance, the first species to show up form the **pioneer** or **early successional community**. Ragweed, crabgrass and most other weeds are often first to arrive. Their seeds, blown in on the wind or carried by animals, germinate and start to grow. By being the first to colonize a new habitat and by growing quickly, pioneer species often inhibit the growth of other species. Their dominance, however, is usually short-lived. Pioneer species gradually change the biotic and abiotic environment in which they live. Plants, for example, create shade, redistribute nutrients, alter moisture levels, and hold the soil in place. The changes pioneer species make often cause the environment to be less suitable for their own existence. These changes, however, create favorable conditions for the next successional stage of species. This happens over and over, each successional stage paving the way for the next, until succession ends with a **climax community**. Climax communities remain unchanged until they are destroyed by disturbance, at which point succession begins again.

Until this point, we've considered succession as a sequence of changes in the plant community of a disturbed area. We must remember, however, that succession also brings changes in the animal, fungal and microbial communities. Following logging, early successional animals, such as quail, indigo buntings and cottontail rabbits, were gradually replaced as the forest matured by late successional species, such as wood thrushes, pileated woodpeckers and flying squirrels *(Figure 8.12)*. Why? Early successional animals are adapted to the habitat created by early successional plants; late successional animals are adapted to the habitat created by late successional plants.

The frequency and intensity of disturbance affects a community's biodiversity. Frequent and intense disturbances tend to lower biodiversity, because only those species that can quickly recolonize and reproduce can survive the ever-changing conditions. Likewise, if disturbances are infrequent or of low intensity, biodiversity tends to be low because only species that can outcompete others survive. Biodiversity, then, is generally highest when disturbance is moderately frequent and moderately intense.

Early and late successional species have different adaptations.

What's the difference between ragweed and a red oak? If we examine each plant's physical appearance, we would say that the weed is low-growing, while the tree is tall. We would notice that ragweed is herbaceous while the oak is woody. Upon closer inspection, we might observe that ragweed, for its size, has an enormous number of tiny seeds. For its part, the oak has bigger seeds, but relatively few if we account for the tree's enormous size. If we were to plant both seeds and track their growth, we would learn that ragweed almost leaps out of the ground, while the oak grows s-l-o-w-l-y. The ragweed is, of course, a pioneer species and the oak a climax species. The tortoise-and-hare nature of how these plants disperse, grow and reproduce paints a picture of the different adaptations displayed by early and late successional species.

Early successional species disperse easily and quickly. They accomplish this by producing many small seeds that can be carried by wind or water. In addition, seeds of early successional species can remain dormant in the soil for years until a disturbance creates the bare-soil conditions required for germination. Early successional species germinate, grow and reproduce quickly. Because they often accomplish this in a single growing season, early successional species rarely reach towering heights or put on the woody tissues of longer-lived species. Their objective is to reproduce as quickly as possible before environmental conditions change.

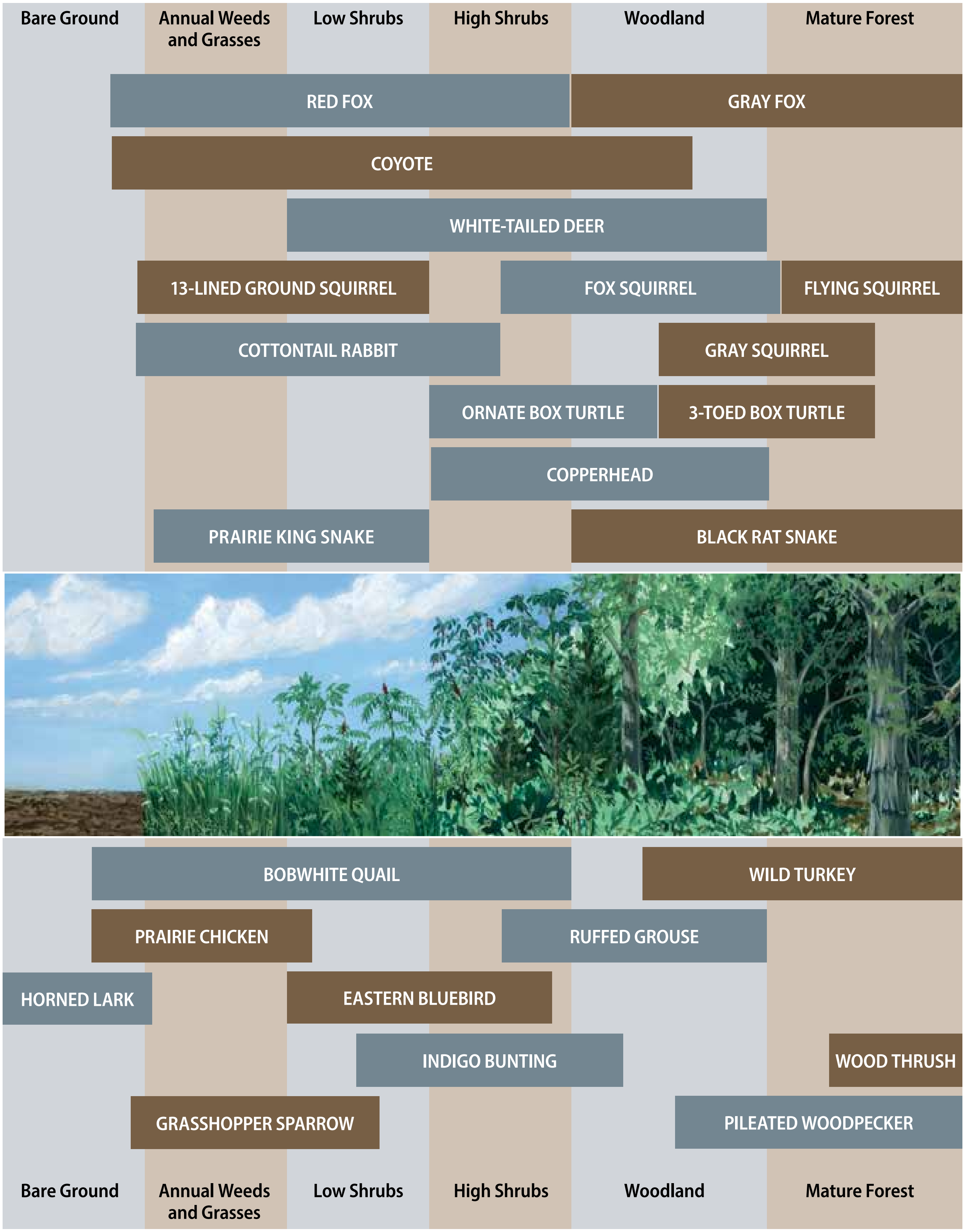


Figure 8.12—As succession progresses, the plant and animal species in a community change.

Characteristic	Early Successional Plant	Late Successional Plant
Number of seeds	many	few
Seed size	small	large
Dispersal	wind, water, stuck to animals	gravity, eaten by animals
Seed viability	long, survives in seed bank	short
Growth rate	rapid	slow
Mature size	small	large
Shade tolerance	low	high

Table 8.3—A Comparison of Early and Late Successional Plants

Ragweed is an early successional species, while an oak tree is a late successional species.

In contrast, the seeds of late successional species are relatively large. This provides their seedlings with plenty of nutrients to start growing in the shady, competitive conditions of the forest floor. Late successional species grow slower than early successional species because they allocate more growth to their roots and stems. This gives them a competitive advantage in the long run. With an abundance of roots to gather water and nutrients, and a towering stem to put leaves closer to sunlight, late successional species eventually outcompete early successional species for water, nutrients and sunlight. Thus, succession is accompanied by a shift from adaptations that promote dispersal, fast growth and reproduction to adaptations that enhance an organism's ability to compete for scarce resources. Table 8.3 compares the characteristics of early and late successional plants. ▲

Setting Back Succession

How do you keep a prairie full of grass? One of the best ways is to set it on fire.

Missouri is at the crossroads of two of North America's largest biomes, the eastern deciduous forest and the tallgrass prairie of the plains. The line between these two biomes divides Missouri almost in half, with prairie communities dominating the north half of the state, and forest communities dominating the south half of the state. This forest-prairie edge shifts based on rainfall and fire frequency. Missouri typically averages 96 centimeters of rainfall per year. Without periodic fires, trees advance into a prairie and shade out grasses and wildflowers. During a drought, however, fires can kill hardwood seedlings and open up areas so grasses can grow. You might say that in the case of prairies, disturbance maintains the climax community of grasses, while with forests, fires and other disturbances initiate succession.

In the past, Native Americans played a role in keeping grasslands open by purposely setting fires from time to time. Today, resource managers set controlled fires to keep trees and shrubs out of grasslands. The reason fire benefits prairie plants and harms forest plants has to do with how the plants grow. Most prairie plants grow from underground roots and rhizomes, which are usually safe from fire. In contrast, most forest plants grow from the tips of their stems and branches, which are often damaged by fire.

Managers boost biodiversity on prairies by setting fires at different times of the year. Burns in late winter or late summer favor wildflowers, cool-season grasses and woody shrubs. Burns in April and May favor warm-season grasses and help control woody plants.

Periodic fires are good for wildlife, too. By stimulating plant diversity, fire provides more food, shelter and nesting areas for animals. Fire removes plant litter on the ground making it easier for quail and other animals to move and find insects. And, fire creates bare areas where birds and small mammals take dust baths and reptiles and amphibians can warm up on cool days.

Resource managers use controlled fire to increase the biodiversity of prairies.

Abiotic—Nonliving. The parts of nature composed of physical and chemical components of the environment, including water, sunlight, temperature and soil chemistry. Page 4.

Adaptation—A specialized structure or behavior that helps an organism survive in a particular environment. Page 15.

Additive mortality—Death that adds to a population's overall mortality. Additive mortality causes a population's size to decrease over time. Compare with compensatory mortality. Page 37.

Allee effect—A phenomenon that draws small populations toward extinction by affecting behaviors, such as finding mates, that depend on high population densities. Page 65.

Anaerobic—Lacking oxygen. Page 90.

Aquifer—An underground pool of water that collects in the pores and crevices of bedrock. Page 93.

Asexual reproduction—A form of reproduction in which only one parent is needed to produce offspring. Compare with sexual reproduction. Page 17.

Atmosphere—A pool or reservoir composed of all the gases making up the Earth's air. Page 85.

Atom—The most basic unit of all matter. Atoms are the smallest portion of a chemical element that maintains the properties of that element. Page 4.

Background extinction—Normal extinction that occurs at a relatively slow rate and caused by the failure of species to adapt to gradual environmental changes, predation or competition. Also called natural extinction. Page 58.

Bag limit—The number of game animals that can be harvested by a single hunter daily. Page 17.

Batesian mimicry—When a harmless organism looks like a dangerous organism to avoid predation. Compare with Mullerian mimicry. Page 51.

Binary fission—A type of asexual reproduction in which a single cell divides into two separate cells, each a separate organism. Many single-celled organisms, such as bacteria and protists, reproduce using binary fission. Page 17.

Biodiversity—The measure of the variety of species, genes and ecosystems within a particular area. Compare with species richness. Page 101.

Biodiversity hotspot—A healthy, functioning natural community that has high biodiversity. Page 105.

Biological carbon cycle—The movement of carbon atoms through the living parts of ecosystems. Compare with geological carbon cycle. Page 86.

Biomolecule—Large molecules, such as carbohydrates, lipids, proteins and nucleic acids, that form the basic building blocks of cells. Page 85.

Biosphere—The regions of Earth in which life exists; all the ecosystems on earth. Page 8 and 85.

Biotic—Living. The parts of nature composed of plants, animals, fungi, protists and bacteria. Page 4.

Brood parasite—A bird that lays its eggs in another species' nest. The other species often ends up raising the brood parasite's offspring, usually at great cost to the survival of its own offspring. Page 49.

Budding—A form of asexual reproduction in which a mass of cells, called a bud, begins growing on the parent's body. When the bud grows large enough, it breaks off of the parent to form a new organism. Page 17.

Carrying capacity—The number of individuals of a particular population that a given area can support at a given time. Compare with cultural carrying capacity. Page 38.

Cell—The smallest unit of life and the basic building block of all organisms. Some organisms, such as bacteria, consist of one cell; others, such as humans, are made up of trillions of cells. Page 4.

Cellular respiration—The biological process by which organisms use oxygen to release the potential energy stored in glucose. The products of respiration are energy, carbon dioxide and water. Page 71.

Census—A count of every individual in a population. Compare with sample. Page 30.

Climax community—The community that develops at the end of a succession and does not change unless there is a disturbance. Compare with pioneer community. Page 108.

Commensalism—The relationship that exists between organisms when one organism benefits and the other is unaffected by the interaction. Page 52.

Community—A group of different populations that live and interact in the same place at the same time. Page 6 and 98.

Community management—Resource management that focuses on entire biological communities. Compare with featured-species management. Page 105.

Community structure and function—A shorthand way for an ecologist to refer to the number, variety and kinds of species that make up a community and the variety of ways those species interact. Page 98.

Compensatory mortality—Different causes of death that make up for mortality that would naturally occur in a population. Compensatory mortality does not cause a population's size to decrease over time. Compare with additive mortality. Page 37.

Competition—An interaction between organisms in which neither organism benefits; a struggle among organisms to use or consume a limited resource. Page 41.

Competitive exclusion principle—The idea that two species with identical niches cannot coexist over time. Also called Gause's Law. Page 47.

Compound—A molecule that contains at least two different elements. Page 84.

Condensation—The change of state of water from gas to liquid. Page 93.

Conservation opportunity area—A biodiversity hotspot within Missouri that has been identified for community management. Page 105.

Consumer—Organisms that can't transform sunlight into usable energy and must eat other organisms to survive. Page 73.

Control group—The parts of an experiment that are not manipulated. Compare with experimental group. Page 9.

Cultural carrying capacity—The population size for a given area that humans will tolerate. Compare with carrying capacity. Page 39.

Decomposer—An organism that breaks biomolecules found in the tissues of dead organisms into simpler molecules that can be used by producers during photosynthesis. Page 75.

Denitrification—The process in which nitrogen is removed from the biosphere, geosphere, and hydrosphere and returned to the atmosphere. Page 90.

Density-dependent factor—A limiting factor that affects a population in ways related to how crowded the population is. Compare with density-independent factor. Page 36.

Density-independent factor—A limiting factor that affects a population regardless of how crowded the population is. Compare with density-dependent factor. Page 36.

Dependent variable—The part of an experiment that is not manipulated, but that reacts to changes made to the independent variable. Compare with independent variable. Page 9.

Detritivore—An organism that gets energy by feeding on dead organisms. Page 75.

Differential reproduction—When some individuals in a population survive and reproduce at higher rates than other individuals in the same population. Page 22.

Dispersion—The spacing of individuals in a population in relation to each other. Page 28.

Disturbance—A departure from the typical environmental conditions of a community. Page 108.

Diversity index—A method used by ecologists to quantify species richness and abundance within a community. Ecologists use diversity indices to compare the biodiversity of one community to another. Page 100.

Early successional community—See pioneer community.

Ecosystem—A community along with the abiotic parts of the environment. Page 7.

Element—A particular kind of atom based on the number of protons found in the atom's nucleus. Carbon, oxygen and nitrogen are elements. Page 84.

Element cycling—The process by which atoms move through ecosystems over and over again. Page 83.

Emigration—Movement of individuals out of an area. Emigration subtracts from population size. Compare with immigration. Page 32.

Endangered—A species that is at risk of going extinct in the near future. Page 60.

Energy—The ability to do work or produce change. Organisms need energy to carry out processes necessary for growth, survival and reproduction. See also kinetic energy and potential energy. Page 70.

Energy flow—The transfer of energy from one organism to another. Page 73.

Energy pyramid—A diagram in the shape of a pyramid that depicts how much energy is available at each trophic level. Page 79.

Equilibrium model of island biogeography—The idea that species richness is a balance between immigration of new species into a community and extirpation of existing species from a community. Page 106.

Equilibrium point—The point in the equilibrium model of island biogeography at which the rate of immigration is balance by the rate of extirpation. The number of different species an island or block of habitat can support. Page 107.

Eutrophication—The build-up of nitrogen and phosphorus in rivers, lakes and oceans. Eutrophication stimulates the growth of large amounts of algae, aquatic plants and other producers. When these organisms die, decomposition removes oxygen from the water, causing other aquatic organisms to die. Page 93.

Evaporation—The movement of water from the geosphere and hydrosphere to the atmosphere. Page 93.

Exotic species—See non-native species.

Experimental group—The parts of an experiment that are manipulated or changed in some way. Compare with control group. Page 9.

Exploitation—An interaction between organisms in which one organism benefits and the other is harmed. Predation, herbivory and parasitism are examples of exploitation. Page 41.

Exponential growth—A period of growth during which a population increases by multiplication rather than addition; when a population increases in proportion to its size. Page 33.

Extinction—When an entire species disappears completely from Earth. Compare with extirpation. Page 57.

Extirpation—When a species disappears from one location but survives in another. Compare with extinction. Page 58.

Featured-species management—Resource management that focuses on a specific species—often a game animal or economically important species. Compare with community management. Page 105.

Food chain—An illustration of how energy is transferred from a producer through various consumers. Page 73.

Food web—A complex illustration that shows all the possible pathways energy could take as it is transferred from producers through consumers in a community; a summary of energy flow in a community. Page 75.

Fragmentation—The carving of large blocks of habitat into smaller, scattered pieces. Page 60.

Fundamental niche—All the environmental conditions a species can tolerate and all the resources it is capable of using under ideal conditions. Compare with realized niche. Page 45.

Gene—Sections of DNA that give instructions to create specific traits. Page 18.

Generalist—A species that can survive in a broad range of habitats and environmental conditions. Compare with specialist. Page 65.

Genetic bottleneck—When a population loses so much genetic diversity it cannot adapt to drastic environmental changes. Page 23.

Genetic homogeneity—When all the members of a population have similar genetic blueprints. Page 21.

Geological carbon cycle—The movement of carbon atoms through the geosphere, atmosphere and hydrosphere. Compare with biological carbon cycle. Page 86.

Geosphere—A pool or reservoir composed of all the rocks and minerals making up the Earth's land. Page 85.

Greenhouse gases—Carbon-based gases, such as carbon dioxide and methane. They allow sunlight to pass through but trap heat. Page 94.

Herbivore—An organism that gets energy by eating plants. Page 48.

Host—The organism a parasite feeds upon or exploits. Page 48.

Hydrosphere—A pool or reservoir composed of all the water in the Earth's oceans, rivers and lakes. Page 85.

Hypothesis—A best guess, based on observations, to answer a specific scientific question. Page 9.

Immigration—Movement of individuals into an area. Immigration adds to population size. Compare with emigration. Page 32.

Inbreeding—Mating among closely related individuals that results in populations with low genetic variation. Page 23.

Independent variable—The part of an experiment that is changed or manipulated in some way. Compare with dependent variable. Page 9.

Indirect competition—Competition caused by organisms trying to gather as much as they can of a shared resource before it runs out. Page 42.

Interaction—A relationship between two or more organisms that affects the growth, survival or reproduction of the participants. Page 41.

Interspecific competition—Competition among different species. Compare with intraspecific competition. Page 42.

Intraspecific competition—Competition among members of the same species. Compare with interspecific competition. Page 42.

Introduced species—A non-native species that humans introduced into an environment in which it previously did not exist. Page 62.

Invasive species—A non-native species that spreads rapidly and harms native organisms. Page 62.

Keystone species—A species that, despite its often low abundance, has a dramatic effect on a community. Page 76.

Kinetic energy—Energy in motion or energy that creates change. Compare with potential energy. Page 70.

Law of conservation of matter—Matter cannot be created or destroyed. Page 86.

Life table—A spreadsheet that helps an ecologist predict how populations will change over time. Page 34.

Limiting factor—A part of an ecosystem that slows or prevents population growth. Page 35.

Lincoln-Peterson estimate—A simple method of mark-recapture sampling. Page 29.

Mark-recapture—A sampling method used to estimate population size in which individuals are caught, marked in some way, and released back into the population. After time has passed, another group of individuals is caught and checked for marks. Page 29.

Mass extinction—The dying off of a large number of species in a relatively short span of time. Page 58.

Mimic—A harmless organism that looks like a dangerous one to avoid predation. Compare with model. Page 51.

Model—A dangerous organism that a mimic resembles. Compare with mimic. Page 51.

Molecule—A combination of two or more atoms. Page 84.

Müllerian mimicry—When dangerous or distasteful species resemble each other. Compare with Batesian mimicry. Page 51.

Mutation—A mistake made when DNA is copied during cell division. This results in a genetic blueprint different from the original. Page 21.

Mutualism—The relationship that exists between organisms when both organisms benefit from the interaction. Page 41.

Mycelia—Tiny, thread-like organs of fungi that gather water and nutrients. Page 89.

Mycorrhizae—A mutualistic relationship between plants and fungi. Plants provide fungi with carbohydrates. In return, fungi gather phosphates and other nutrients for use by plants. Page 89.

Natural extinction—See background extinction.

Natural resource manager—A trained professional who works to protect, maintain and restore healthy ecosystems. Page 10.

Natural selection—The process through which organisms become adapted to their environment over time. Page 24.

Niche—An organism's way of life and role in its environment. Everything that affects a particular organism's existence, including the range of environmental conditions the organism can tolerate, what the organism needs to survive, and the organism's interaction with the biotic and abiotic parts of its environment. Page 45.

Nitrification—The process that converts ammonia into nitrates. Page 90.

Nitrogen fixation—The process that converts nitrogen gas into ammonia. In most instances, nitrogen must be fixed before living things can use it. Page 90.

Non-native species—An organism that has recently—within the past 200 years—moved into an area in which it previously did not exist. Page 62.

Organ—A group of tissues working together to perform a specific function. Page 4.

Organelle—Microscopic structures in a cell that perform specific functions. Page 4.

Organism—A single living thing. Page 5.

Parasite—An organism that gets energy by feeding on the blood, intestinal fluids or tissues of another organism. Page 48.

Parthenogenesis—A form of asexual reproduction in which eggs from a female develop into offspring without being fertilized by a male. Page 17.

Per capita rate of growth—Population change expressed on an individual-by-individual basis; the amount a single individual contributes to population growth or decline. Page 34.

Photosynthesis—A process used by plants, algae and some bacteria to transform the kinetic energy of sunlight into the potential energy of glucose. In the process, six molecules of carbon dioxide and six molecules of water are transformed into one molecule of glucose and six molecules of oxygen. Page 71.

Pioneer community—The first species that show up after a disturbance. Compare with climax community. Page 108.

Pool—A place where atoms collect for a short length of time, from a few hours to a few years. Page 85.

Population—A group of the same kind of organisms living together in the same place at the same time. Page 6.

Population density—The number of individuals in a population per unit of area. Page 28.

Population sink—An ecosystem in which a particular population's deaths exceed births causing its size to decrease. Page 64.

Population size—The number of individual organisms that make up a population (N). Page 6.

Potential energy—Stored energy. Compare with kinetic energy. Page 70.

Precipitation—The process by which water vapor condenses on microscopic particles in the atmosphere and then falls from the sky. Page 93.

Predator—An organism that gets energy by catching, killing and eating prey. Page 48.

Predator-prey cycle—A series of peaks and valleys in the population sizes of predator and prey species. This results from the fact that prey and predator populations are linked and a change in the size of one population causes change in the other population. Page 55.

Primary production—The process and resulting tissues of plants and other photosynthetic organisms formed when they combine glucose with other molecules. Page 71.

Primary succession—Succession that begins on areas without soil, such as bare rocks, lava flows, and areas scraped lifeless by retreating glaciers. Page 108.

Producer—A plant or other photosynthetic organism that uses sunlight to produce glucose, a form of energy that can be used by most organisms. Page 71.

Realized niche—The portion of a species' fundamental niche that it can use in the presence of other species. Compare with fundamental niche. Page 45.

Recombination—When homologous chromosomes trade genetic information with each other during the formation of eggs and sperm. This causes each egg or sperm to have a genetic blueprint different from the genetic blueprint of its parent cell. Page 21.

Relative abundance—The measure of how abundant one species is compared to all others in a community. Also called species evenness. Page 99.

Reproduction—The process by which new organisms are produced from existing organisms. Page 16.

Reservoir—A place where atoms reside for long periods of time, from decades to millions of years. Page 85.

Resource partitioning—The process by which species with similar niches avoid competitive exclusion by using resources in slightly different ways. Page 47.

Runoff—When precipitation falls to the ground faster than it can soak in and is pulled toward the ocean by gravity. Page 93.

Sample—A count of a small portion of the individuals in a population. Samples are used to estimate the total number of individuals in a population. Compare with census. Page 30.

Secondary succession—A type of succession that occurs when the preceding community is destroyed, but the soil is not. Page 108.

Self-incompatible—A type of plant that cannot pollinate itself. Page 20.

Sexual reproduction—A form of reproduction in which two parents are needed to produce offspring. Compare with asexual reproduction. Page 17.

Slot length limit—A harvest tool in which fish shorter and longer than a certain length range can be harvested, but fish that fall within the length range, or slot, have to be returned to the water unharmed. Page 74.

Specialist—A species that requires specific habitat and a narrow range of environmental conditions to survive. Compare with generalist. Page 65.

Species-area rule—The general idea that large areas harbor more species than small areas. Page 104.

Species diversity—The variety of different species within a community. Page 101.

Species evenness—See relative abundance.

Species richness—The number of different species a community contains. Page 98.

Stand—A segment of a forest. Page 44.

Succession—A sequence in which biological communities are replaced by other biological communities over time. Page 108.

Symbiosis—A close relationship between two organisms in which one organism could not survive without the other. Page 54.

Timber stand improvement—A management technique used by foresters to improve the health and quality of surviving trees by removing unwanted or low-value trees. Page 44.

Tissue—A group of cells that function together to perform a specific task. Page 4.

Transect—A straight line of a known length used to sample a population. Page 30.

Translocation—Taking individuals from thriving populations and releasing them into struggling populations. Page 23.

Transpiration—The process by which plants release excess water into the atmosphere. Page 93.

Trophic level—The position (producer, primary consumer, etc.) an organism occupies in a food chain. Page 78.

Vegetative reproduction—A form of asexual reproduction in which part of a plant—such as its leaves, roots or stem—breaks off and begins growing into a separate plant. Page 17.

Warning coloration—Bold patterns and bright coloration used by organisms to advertise hazardous traits that help them avoid predation. Page 50.

Water cycle—The movement of water through the biosphere, geosphere, hydrosphere and atmosphere. Page 92.

Because most of the world uses the metric system, scientists measure and describe nature using metric units. This makes it easier for scientists from the United States to compare their findings with those of scientists in other countries. Use these charts to convert metric units into English-measurement equivalents.

When You Know	Multiply By	To Get
Length		
Inches	2.54	Centimeters
Feet	0.30	Meters
Miles	1.61	Kilometers
Centimeters	0.39	Inches
Meters	3.28	Feet
Kilometers	0.62	Miles
Area		
Square Inches	6.50	Square Centimeters
Square Feet	0.09	Square Meters
Square Miles	2.6	Square Kilometers
Acres	0.4	Hectares
Square Centimeters	0.16	Square Inches
Square Meters	10.76	Square Feet
Square Kilometers	0.39	Square Miles
Hectares	2.47	Acres
Mass and Weight		
Pounds	0.45	Kilograms
Kilograms	2.22	Pounds
Volume		
Teaspoons	4.93	Milliliters
Quarts	0.95	Liters
Cubic Feet	0.04	Cubic Meters
Milliliters	0.20	Teaspoons
Liters	1.06	Quarts
Cubic Meters	35.31	Cubic Feet

Metric Prefixes*		
Prefix	**Symbol**	**Factor**
Kilo-	k	1,000
Hecto-	h	100
Deca-	da	10
-Base		1
Deci-	d	0.1
Centi-	c	0.01
Milli-	m	0.001

* A metric prefix is a name that precedes a base unit of measurement in the metric system. For example, meters, liters and grams are the base units of length, volume and mass, respectively. Metric prefixes are based on multiples of ten. This makes converting one prefix to another as easy as moving the decimal place. Here's how:

- To convert from a larger prefix to a smaller prefix, move the decimal to the right.
- To convert from a smaller prefix to a larger one, move the decimal to the left.

For example, if you wanted to convert 36 kilometers into centimeters, you would move the decimal five places to the right because there are five factors separating kilometers from centimeters. This would give you 3,600,000 centimeters. Likewise, if you wanted to convert 500 millimeters into meters, you would move the decimal three places to the left and get 0.5 meters. Remember, count the decimal place where you stop, not the one where you start. It takes a bit of practice, but once you get the hang of it, using the metric system is easy!

On the back cover: The biodiversity of Missouri's prairies is staggering, with more than 200 plant species found on as little as 15 hectares. Each of these species—indeed every single organism—interacts with other living things and its environment in countless numbers of ways.

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